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(54) Title: TREATMENT METHODOLOGIES FOR SUBSURFACE HYDROCARBON CONTAINING FORMATIONS

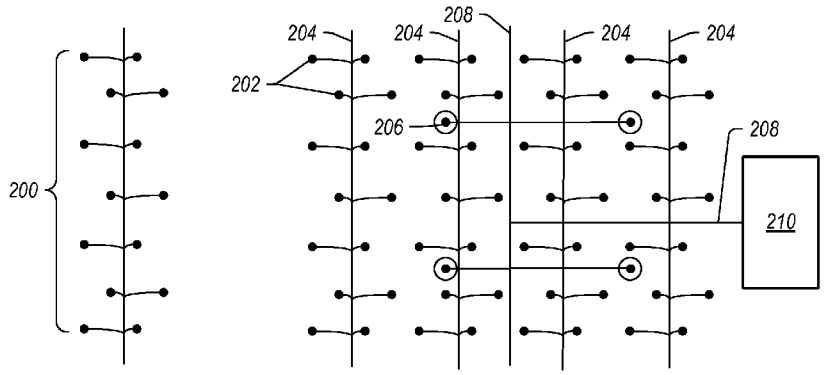


FIG. 1

(57) Abstract: Systems, methods, processes, and/or heaters for treating a subsurface formation are described herein. Some embodiments also generally relate to heaters that have novel components therein. Such heaters may be obtained by using the systems and methods described. Some embodiments also generally relate to systems, methods, and/or processes for treating fluid produced from the subsurface formation.

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TREATMENT METHODOLOGIES FOR SUBSURFACE HYDROCARBON CONTAINING FORMATIONS

BACKGROUND

1. Field of the Invention

[0001] The present invention relates generally to methods and systems for production of hydrocarbons, hydrogen, and/or other products from various subsurface formations such as hydrocarbon containing formations.

2. Description of Related Art

[0002] Hydrocarbons obtained from subterranean formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available hydrocarbon resources and concerns over declining overall quality of produced hydrocarbons have led to development of processes for more efficient recovery, processing and/or use of available hydrocarbon resources. In situ processes may be used to remove hydrocarbon materials from subterranean formations that were previously inaccessible and/or too expensive to extract using available methods. Chemical and/or physical properties of hydrocarbon material in a subterranean formation may need to be changed to allow hydrocarbon material to be more easily removed from the subterranean formation and/or increase the value of the hydrocarbon material. The chemical and physical changes may include in situ reactions that produce removable fluids, composition changes, solubility changes, density changes, phase changes, and/or viscosity changes of the hydrocarbon material in the formation.

[0003] Large deposits of heavy hydrocarbons (heavy oil and/or tar) contained in relatively permeable formations (for example in tar sands) are found in North America, South America, Africa, and Asia. Tar can be surface-mined and upgraded to lighter hydrocarbons such as crude oil, naphtha, kerosene, and/or gas oil. Surface milling processes may further separate the bitumen from sand. The separated bitumen may be converted to light hydrocarbons using conventional refinery methods. Mining and upgrading tar sand is usually substantially more expensive than producing lighter hydrocarbons from conventional oil reservoirs.

[0004] Obtaining permeability in an oil shale formation between injection and production wells tends to be difficult because oil shale is often substantially impermeable. Drilling such wells may be expensive and time consuming. Many methods have attempted to link injection and production wells.

[0005] Many different types of wells or wellbores may be used to treat the hydrocarbon containing formation using an in situ heat treatment process. In some embodiments, vertical

and/or substantially vertical wells are used to treat the formation. In some embodiments, horizontal or substantially horizontal wells (such as J-shaped wells and/or L-shaped wells), and/or u-shaped wells are used to treat the formation. In some embodiments, combinations of horizontal wells, vertical wells, and/or other combinations are used to treat the formation. In certain embodiments, wells extend through the overburden of the formation to a hydrocarbon containing layer of the formation. In some situations, heat in the wells is lost to the overburden. In some situations, surface and overburden infrastructures used to support heaters and/or production equipment in horizontal wellbores or u-shaped wellbores are large in size and/or numerous.

[0006] Wellbores for heater, injection, and/or production wells may be drilled by rotating a drill bit against the formation. The drill bit may be suspended in a borehole by a drill string that extends to the surface. In some cases, the drill bit may be rotated by rotating the drill string at the surface. Sensors may be attached to drilling systems to assist in determining direction, operating parameters, and/or operating conditions during drilling of a wellbore. Using the sensors may decrease the amount of time taken to determine positioning of the drilling systems. For example, U.S. Patent No. 7,093,370 to Hansberry and U.S. Patent Application Publication No. 2009-0207041 to Zaeper et al., both of which are incorporated herein by reference, describe a borehole navigation systems and/or sensors to drill wellbores in hydrocarbon formations. At present, however, there are still many hydrocarbon containing formations where drilling wellbores is difficult, expensive, and/or time consuming.

[0007] Heaters may be placed in wellbores to heat a formation during an in situ process. There are many different types of heaters which may be used to heat the formation. Examples of in situ processes utilizing downhole heaters are illustrated in U.S. Patent Nos. 2,634,961 to Ljungstrom; 2,732,195 to Ljungstrom; 2,780,450 to Ljungstrom; 2,789,805 to Ljungstrom; 2,923,535 to Ljungstrom; 4,886,118 to Van Meurs et al.; and 6,688,387 to Wellington et al.

[0008] U.S. Patent No. 7,575,052 to Sandberg et al. and U.S. Patent Application Publication No. 2008-0135254 to Vinegar et al., each of which are incorporated herein by reference, describe an in situ heat treatment process that utilizes a circulation system to heat one or more treatment areas. The circulation system may use a heated liquid heat transfer fluid that passes through piping in the formation to transfer heat to the formation.

[0009] Patent Application Publication No. 2009-0095476 to Nguyen et al., which is incorporated herein by reference, describes a heating system for a subsurface formation that includes a conduit located in an opening in the subsurface formation. An insulated conductor is located in the conduit. A material is in the conduit between a portion of the insulated conductor and a portion of the conduit. The material may be a salt. The material is a fluid at operating temperature of the

heating system. Heat transfers from the insulated conductor to the fluid, from the fluid to the conduit, and from the conduit to the subsurface formation.

[0010] In situ production of hydrocarbons from tar sand may be accomplished by heating and/or injecting fluids into the formation. U.S. Patent Nos. 4,084,637 to Todd; 4,926,941 to Glandt et al.; 5,046,559 to Glandt, and 5,060,726 to Glandt, each of which are incorporated herein by reference, describe methods of producing viscous materials from subterranean formations that includes passing electrical current through the subterranean formation. Steam may be injected from the injector well into the formation to produce hydrocarbons.

[0011] U.S. Patent No. 3,515,213 to Prats describes circulation of a fluid heated at a moderate temperature from one point within the formation to another for a relatively long period of time until a significant proportion of the organic components contained in the oil shale formation are converted to oil shale derived fluidizable materials.

[0012] U.S. Patent No. 3,882,941 to Pelofsky describes recovering hydrocarbons from oil shale deposits by introducing hot fluids into the deposits through wells and then shutting in the wells to allow kerogen in the deposits to be converted to bitumen which is then recovered through the wells after an extended period of soaking.

[0013] U.S. Patent No. 7,011,154 to Maher et al. describes in situ treatment of a kerogen and liquid hydrocarbon containing formation using heat sources to produce pyrolyzed hydrocarbons. Maher also describes an in situ treatment of a kerogen and liquid hydrocarbon containing formation using a heat transfer fluid such as steam. In an embodiment, a method of treating a kerogen and liquid hydrocarbon containing formation may include injecting a heat transfer fluid into a formation. Heat from the heat transfer fluid may transfer to a selected section of the formation. The heat from the heat transfer fluid may pyrolyze a substantial portion of the hydrocarbons within the selected section of the formation. The produced gas mixture may include hydrocarbons with an average API gravity greater than about 25°.

[0014] During some in situ processes, fluids may be introduced or generated in the formation. Introduced or generated fluids may need to be contained in a treatment area to minimize or eliminate impact of the in situ process on adjacent areas. During some in situ processes, a barrier may be formed around all or a portion of the treatment area to inhibit migration fluids out of or into the treatment area.

[0015] A low temperature zone may be used to isolate selected areas of subsurface formation for many purposes. U.S. Patent Nos. 7,032,660 to Vinegar et al.; 7435037 to McKinzie, II; 7,527,094 to McKinzie et al.; 7,500,528 to McKinzie, II et al.; and 7,631,689 to Vinegar et al., and U.S. Patent Application Publication No. 2008-0217003 to Kulhman et al. and 2008-0185147 to Vinegar et al. describe barrier systems for subsurface treatment areas.

[0016] As discussed above, there has been a significant amount of effort to develop methods and systems to economically produce hydrocarbons, hydrogen, and/or other products from hydrocarbon containing formations. At present, however, there are still many hydrocarbon containing formations from which hydrocarbons, hydrogen, and/or other products cannot be economically produced. Thus, there is a need for improved methods and systems for heating of a hydrocarbon formation and production of fluids from the hydrocarbon formation. There is also a need for improved methods and systems that reduce energy costs for treating the formation, reduce emissions from the treatment process, facilitate heating system installation, and/or reduce heat loss to the overburden as compared to hydrocarbon recovery processes that utilize surface based equipment.

SUMMARY

[0017] Embodiments described herein generally relate to systems, methods, and heaters for treating a subsurface formation. Embodiments described herein also generally relate to heaters that have novel components therein. Such heaters can be obtained by using the systems and methods described herein.

[0018] In certain embodiments, the invention provides one or more systems, methods, and/or heaters. In some embodiments, the systems, methods, and/or heaters are used for treating a subsurface formation.

[0019] In certain embodiments, a method for treating a tar sands formation includes: providing heat from a first heater located between a steam injection well and a production well in a hydrocarbon containing layer of the formation, wherein the first heater, the steam injection well, and the production well are located substantially horizontally in the hydrocarbon containing layer; providing heat from a second heater horizontally offset from the first heater, the second heater being located vertically above an injection/production well in the hydrocarbon containing layer, the second heater being located substantially horizontally in the hydrocarbon containing layer; injecting steam into the hydrocarbon containing layer through the steam injection well after a selected amount of heat is provided from the first heater; producing hydrocarbons from the layer through the production well; and alternately injecting steam and producing hydrocarbons through the injection/production well after a selected amount of heat is provided from the second heater.

[0020] In certain embodiments, a method for treating a tar sands formation includes: providing heat from a first heater located between a steam injection well and a production well in a hydrocarbon containing layer of the formation, wherein the first heater, the steam injection well, and the production well are located substantially horizontally in the hydrocarbon containing

layer; injecting steam into the hydrocarbon containing layer through the steam injection well after a selected amount of heat is provided from the first heater; and producing hydrocarbons from the layer through the production well.

[0021] In certain embodiments, a method of recovering energy from a subsurface hydrocarbon containing formation includes: introducing an oxidizing fluid in a wellbore positioned in at least a first portion of a subsurface hydrocarbon containing formation, wherein at least a portion of the first portion of the subsurface hydrocarbon containing formation has been subjected to an in situ heat treatment process prior to introduction of the oxidizing fluid, and wherein the portion comprises a treatment area comprising elevated levels of coke substantially adjacent the wellbore; increasing the pressure in the wellbore by introducing the oxidizing fluid under pressure such that the oxidizing fluid substantially permeates a majority of the treatment area and initiates a combustion process; allowing heat from the combustion process to transfer to fluids in the treatment area; decreasing the pressure in the wellbore such that heated fluids from the portion of the formation are conveyed into the wellbore; and transferring heated fluids conveyed into the wellbore to the surface to a heat exchanger configured to collect thermal energy.

[0022] In certain embodiments, a method of recovering energy from a subsurface hydrocarbon containing formation includes: introducing an oxidizing fluid in a wellbore positioned in at least a first portion of a subsurface hydrocarbon containing formation, wherein at least a portion of the first portion of the subsurface hydrocarbon containing formation has been subjected to an in situ heat treatment process prior to introduction of the oxidizing fluid, and wherein the portion comprises a treatment area comprising elevated levels of coke substantially adjacent the wellbore; increasing the pressure in the wellbore by introducing the oxidizing fluid under pressure such that the oxidizing fluid substantially permeates a majority of the treatment area and initiates a combustion process; allowing heat from the combustion process to transfer to fluids in the treatment area; decreasing the pressure in the wellbore such that at least some heated fluids from the treatment area are conveyed into the wellbore; and introducing a heat transfer fluid in the wellbore such that heat is transferred from the wellbore to the heat transfer fluid.

[0023] In certain embodiments, a method of heating a subsurface hydrocarbon containing formation includes: providing heat flux per volume to a first portion of a subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more first heat sources positioned in the first portion; and providing heat flux per volume to a second portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more second heat sources positioned in the second portion, wherein the heat flux per volume provided by the two or more second heat sources is greater than the heat flux per volume

provided by the two or more first heat sources, and wherein the second portion is positioned below the first portion.

[0024] In certain embodiments, a system for heating a subsurface formation includes: a heater wellbore located in a subsurface formation; a single conducting heater element comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and a heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising an electrically non-conducting portion and an electrically conducting portion; wherein the non-conducting portion begins at the surface of the formation, the conducting portion is located between the non-conducting portion and the heated portion of the heater, and the non-conducting portion extends to a depth that is at least about 30 m above the heated portion of the heater.

[0025] In certain embodiments, a system for heating a subsurface formation includes: a heater wellbore located in a subsurface formation; a heater comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden, and the heated part comprises a single conducting element; and a heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising an electrically non-conducting portion and an electrically conducting portion; wherein the non-conducting portion begins at the surface of the formation, the conducting portion is located between the non-conducting portion and the heated portion of the heater, and the non-conducting portion extends to a depth of at least about 10 m below the surface.

[0026] In certain embodiments, a system for heating a subsurface formation includes: a heater wellbore located in a subsurface formation; a single conducting heater element comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and a heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising an electrically non-conducting portion and an electrically conducting portion; wherein the non-conducting portion begins at the surface of the formation, the conducting portion is located between the nonconducting portion and the heated portion of the heater, and the nonconducting portion extends to at least to a depth that is at least below a surface moisture zone of the formation.

[0027] In certain embodiments, a system for heating a subsurface formation includes: a first heater wellbore in a plurality of heater wellbores located in a subsurface formation, the first heater wellbore comprising: a first single conducting heater element comprising a heated portion

located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and a first heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising a first electrically non-conducting portion and a first electrically conducting portion, wherein the first conducting portion is located between the first non-conducting portion and the heated portion of the heater; and a second heater wellbore of a plurality of heater wellbores, the second heater wellbore adjacent to the first heater wellbore, the second heater wellbore comprising: a second single conducting heater element comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden and the second single conducting heater element has a polarity opposite of the first single conducting heater element; and a second heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising a second electrically non-conducting portion and a second electrically conducting portion, wherein the second conducting portion is located between the second non-conducting portion and the heated portion of the heater; wherein the first and second non-conducting portions extend to depths at least twice a distance between the first wellbore and the second wellbore.

[0028] In certain embodiments, a heating system for a subsurface formation includes: a first tubular located in the subsurface formation; a second tubular, wherein at least a portion of the first tubular is positioned in the second tubular; and two or more elongated electrical conductors, wherein at least a portion of the electrical conductors are positioned between an outer surface of the first tubular and an inner surface of the second tubular; wherein the electrical conductors are configured to provide heat to the subsurface formation when an electrical current is applied to the electrical conductors.

[0029] In certain embodiments, a system for producing fluids from a subsurface formation includes: a wellbore in the subsurface formation, wherein the wellbore is configured to allow fluids from the formation to enter a substantially horizontal section of the wellbore; a first tubular located in the wellbore, wherein the first tubular has an opening at an end of the first tubular distal from the surface of the formation; a second tubular in the wellbore, wherein at least a portion of the first tubular is positioned in the second tubular; and two or more elongated electrical conductors, wherein at least a portion of the electrical conductors are positioned between an outer surface of the first tubular and an inner surface of the second tubular; wherein the electrical conductors are configured to provide heat in the wellbore when an electrical current is applied to the electrical conductors; and wherein the system is configured to produce fluids that enter the wellbore to the surface of the formation through the inside of the first tubular.

[0030] In certain embodiments, a method for producing fluids from a subsurface formation includes: allowing fluids to enter a substantially horizontal section of a wellbore in the subsurface formation; producing at least some of the fluids through the inside of a first tubular located in the wellbore, wherein the produced fluids enter the first tubular through an opening located at an end of the first tubular distal from the surface of the formation; and providing heat to at least a part of the substantially horizontal section of the wellbore by applying electrical current to two or more electrical conductors positioned between the outer surface of the first tubular and the inner surface of a second tubular that at least partially surrounds the first tubular.

[0031] In further embodiments, features from specific embodiments may be combined with features from other embodiments. For example, features from one embodiment may be combined with features from any of the other embodiments.

[0032] In further embodiments, treating a subsurface formation is performed using any of the methods, systems, or heaters described herein.

[0033] In further embodiments, additional features may be added to the specific embodiments described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description and upon reference to the accompanying drawings in which:

[0035] FIG. 1 shows a schematic view of an embodiment of a portion of an in situ heat treatment system for treating a hydrocarbon containing formation.

[0036] FIG. 2 depicts a schematic representation of an embodiment of a system for treating a liquid stream produced from an in situ heat treatment process.

[0037] FIG. 3 depicts a schematic representation of an embodiment of a system for forming and transporting tubing to a treatment area.

[0038] FIG. 4 depicts a schematic of an embodiment of a first group of barrier wells used to form a first barrier and a second group of barrier wells used to form a second barrier.

[0039] FIG. 5 depicts a schematic representation of an embodiment of a dual barrier system.

[0040] FIG. 6 depicts a schematic representation of another embodiment of a dual barrier system.

[0041] FIG. 7 depicts a cross-sectional view of an embodiment of a dual barrier system used to isolate a treatment area in a formation.

[0042] FIG. 8 depicts a cross-sectional view of an embodiment of a breach in a first barrier of dual barrier system.

[0043] FIG. 9 depicts a cross-sectional view of an embodiment of a breach in second barrier of dual barrier system.

[0044] FIG. 10 depicts a representation of an embodiment of forming a bitumen barrier in a subsurface formation.

[0045] FIG. 11 depicts a representation of another embodiment of forming a bitumen barrier in a subsurface formation.

[0046] FIGS. 12, 13, and 14 depict cross-sectional representations of an embodiment of a temperature limited heater with an outer conductor having a ferromagnetic section and a non-ferromagnetic section.

[0047] FIGS. 15, 16, 17, and 18 depict cross-sectional representations of an embodiment of a temperature limited heater with an outer conductor having a ferromagnetic section and a non-ferromagnetic section placed inside a sheath.

[0048] FIGS. 19A and 19B depict cross-sectional representations of an embodiment of a temperature limited heater.

[0049] FIG. 20 depicts a cross-sectional representation of an embodiment of a composite conductor with a support member.

[0050] FIG. 21 depicts a cross-sectional representation of an embodiment of a composite conductor with a support member separating the conductors.

[0051] FIG. 22 depicts a cross-sectional representation of an embodiment of a composite conductor surrounding a support member.

[0052] FIG. 23 depicts a cross-sectional representation of an embodiment of a composite conductor surrounding a conduit support member.

[0053] FIG. 24 depicts a cross-sectional representation of an embodiment of a conductor-in-conduit heat source.

[0054] FIG. 25 depicts a cross-sectional representation of an embodiment of a removable conductor-in-conduit heat source.

[0055] FIG. 26 depicts a cross-sectional representation of an embodiment of a temperature limited heater in which the support member provides a majority of the heat output below the Curie temperature of the ferromagnetic conductor.

[0056] FIGS. 27 and 28 depict cross-sectional representations of embodiments of temperature limited heaters in which the jacket provides a majority of the heat output below the Curie temperature of the ferromagnetic conductor.

[0057] FIGS. 29A and 29B depict cross-sectional representations of an embodiment of a temperature limited heater component used in an insulated conductor heater.

[0058] FIG. 30 depicts an embodiment of an insulated conductor with a semiconductor layer adjacent to and surrounding a core.

[0059] FIG. 31 depicts an embodiment of an insulated conductor with a semiconductor layer inside an electrical insulator and surrounding a core.

[0060] FIG. 32 depicts an embodiment of a tapered portion of an insulated conductor.

[0061] FIG. 33 depicts an embodiment of tapered an insulated conductor in an opening.

[0062] FIG. 34 depicts an embodiment of tapered an insulated conductor in a hairpin configuration.

[0063] FIG. 35 depicts an embodiment of a tapered insulated conductor with a core coupled (shorted) to a jacket with a termination.

[0064] FIG. 36 depicts a top view representation of three insulated conductors in a conduit.

[0065] FIG. 37 depicts an embodiment of three-phase wye transformer coupled to a plurality of heaters.

[0066] FIG. 38 depicts a side view representation of an embodiment of an end section of three insulated conductors in a conduit.

[0067] FIG. 39 depicts an embodiment of a heater with three insulated cores in a conduit.

[0068] FIG. 40 depicts an embodiment of a heater with three insulated conductors and an insulated return conductor in a conduit.

[0069] FIG. 41 depicts a side view cross-sectional representation of one embodiment of a fitting for joining insulated conductors.

[0070] FIG. 42 depicts an embodiment of a cutting tool.

[0071] FIG. 43 depicts a side view cross-sectional representation of another embodiment of a fitting for joining insulated conductors.

[0072] FIG. 44A depicts a side view of a cross-sectional representation of an embodiment of a threaded fitting for coupling three insulated conductors.

[0073] FIG. 44B depicts a side view of a cross-sectional representation of an embodiment of a welded fitting for coupling three insulated conductors.

[0074] FIG. 45 depicts an embodiment of a torque tool.

[0075] FIG. 46 depicts an embodiment of a clamp assembly that may be used to compact mechanically a fitting for joining insulated conductors.

[0076] FIG. 47 depicts an exploded view of an embodiment of a hydraulic compaction machine.

[0077] FIG. 48 depicts a representation of an embodiment of an assembled hydraulic compaction machine.

[0078] FIG. 49 depicts an embodiment of a fitting and insulated conductors secured in clamp assemblies before compaction of the fitting and insulated conductors.

[0079] FIG. 50 depicts a side view representation of yet another embodiment of a fitting for joining insulated conductors.

[0080] FIG. 51 depicts a side view representation of an embodiment of a fitting with an opening covered with an insert.

[0081] FIG. 52 depicts an embodiment of a fitting with electric field reducing features between the jackets of the insulated conductors and the sleeves and at the ends of the insulated conductors.

[0082] FIG. 53 depicts an embodiment of an electric field stress reducer.

[0083] FIG. 54 depicts a cross-sectional representation of a fitting as insulated conductors are being moved into the fitting.

[0084] FIG. 55 depicts a cross-sectional representation of a fitting with insulated conductors joined inside the fitting.

[0085] FIGS. 56, 57, and 58 depict an embodiment of a block pushing device that may be used to provide axial force to blocks in a heater assembly.

[0086] FIG. 59 depicts an embodiment of a plunger with a cross-sectional shape that allows the plunger to provide force on the blocks but not on the core inside the jacket.

[0087] FIG. 60 depicts an embodiment of a plunger that may be used to push offset (staggered) blocks.

[0088] FIG. 61 depicts an embodiment of a plunger that may be used to push top/bottom arranged blocks.

[0089] FIG. 62 depicts an embodiment of an outer tubing partially unspooled from a coiled tubing rig.

[0090] FIG. 63 depicts an embodiment of a heater being pushed into outer tubing partially unspooled from a coiled tubing rig.

[0091] FIG. 64 depicts an embodiment of a heater being fully inserted into outer tubing with a drilling guide coupled to the end of the heater.

[0092] FIG. 65 depicts an embodiment of a heater, outer tubing, and drilling guide spooled onto a coiled tubing rig.

[0093] FIG. 66 depicts an embodiment of a coiled tubing rig being used to install a heater and outer tubing into an opening using a drilling guide.

[0094] FIG. 67 depicts an embodiment of a heater and outer tubing installed in an opening.

[0095] FIG. 68 depicts an embodiment of outer tubing being removed from an opening while leaving a heater installed in the opening.

[0096] FIG. 69 depicts an embodiment of outer tubing used to provide a packing material into an opening.

[0097] FIG. 70 depicts a schematic of an embodiment of outer tubing being spooled onto a coiled tubing rig after packing material is provided into an opening.

[0098] FIG. 71 depicts a schematic of an embodiment of outer tubing spooled onto a coiled tubing rig with a heater installed in an opening.

[0099] FIG. 72 depicts an embodiment of a heater installed in an opening with a wellhead.

[0100] FIG. 73 depicts an embodiment of heaters being helically wound on a spool.

[0101] FIG. 74 depicts an embodiment of three heaters helically wound together.

[0102] FIG. 75 depicts an embodiment of three heaters helically wound around a support.

[0103] FIG. 76 depicts a cross-sectional representation of an embodiment of an insulated conductor in a conduit with liquid between the insulated conductor and the conduit.

[0104] FIG. 77 depicts a cross-sectional representation of an embodiment of an insulated conductor heater in a conduit with a conductive liquid between the insulated conductor and the conduit.

[0105] FIG. 78 depicts a schematic representation of an embodiment of an insulated conductor in a conduit with liquid between the insulated conductor and the conduit, where a portion of the conduit and the insulated conductor are oriented horizontally in the formation.

[0106] FIG. 79 depicts a cross-sectional representation of an embodiment of a ribbed conduit.

[0107] FIG. 80 depicts a perspective representation of an embodiment of a portion of a ribbed conduit.

[0108] FIG. 81 depicts a cross-sectional representation an embodiment of a portion of an insulated conductor in a bottom portion of an open wellbore with a liquid between the insulated conductor and the formation.

[0109] FIG. 82 depicts a schematic cross-sectional representation of an embodiment of a portion of a formation with heat pipes positioned adjacent to a substantially horizontal portion of a heat source.

[0110] FIG. 83 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with the heat pipe located radially around an oxidizer assembly.

[0111] FIG. 84 depicts a cross-sectional representation of an angled heat pipe embodiment with an oxidizer assembly located near a lowermost portion of the heat pipe.

[0112] FIG. 85 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with an oxidizer located at the bottom of the heat pipe.

[0113] FIG. 86 depicts a cross-sectional representation of an angled heat pipe embodiment with an oxidizer located at the bottom of the heat pipe.

[0114] FIG. 87 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with an oxidizer that produces a flame zone adjacent to liquid heat transfer fluid in the bottom of the heat pipe.

[0115] FIG. 88 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with a tapered bottom that accommodates multiple oxidizers.

[0116] FIG. 89 depicts a cross-sectional representation of a heat pipe embodiment that is angled within the formation.

[0117] FIG. 90 depicts an embodiment of three heaters coupled in a three-phase configuration.

[0118] FIG. 91 depicts a side view representation of an embodiment of a substantially u-shaped three-phase heater in a formation.

[0119] FIG. 92 depicts a top view representation of an embodiment of a plurality of triads of three-phase heaters in a formation.

[0120] FIG. 93 depicts a top view representation of an embodiment of a plurality of triads of three-phase heaters in a formation with production wells.

[0121] FIG. 94 depicts a schematic of an embodiment of a heat treatment system that includes a heater and production wells.

[0122] FIG. 95 depicts a side view representation of one leg of a heater in the subsurface formation.

[0123] FIG. 96 depicts a schematic representation of an embodiment of a surface cabling configuration with a ground loop used for a heater and a production well.

[0124] FIG. 97 depicts a side view representation of an embodiment of an overburden portion of a conductor.

[0125] FIG. 98 depicts a side view representation of an embodiment of overburden portions of conductors grounded to a ground loop.

[0126] FIG. 99 depicts a side view representation of an embodiment of overburden portions of conductors with the conductors ungrounded.

[0127] FIG. 100 depicts a side view representation of an embodiment of overburden portions of conductors with the electrically conductive portions of casings lowered a selected depth below the surface.

[0128] FIGS. 101 and 102 depict cross-sectional representations of embodiments of heaters including three single-phase conductors positioned between first tubulars and second tubulars.

[0129] FIG. 103 depicts a cross-sectional representation of an embodiment of a heater including nine single-phase flexible cable conductors positioned between tubulars.

[0130] FIG. 104 depicts a cross-sectional representation of an embodiment of a heater including nine single-phase flexible cable conductors positioned between tubulars with spacers.

[0131] FIG. 105 depicts a cross-sectional representation of an embodiment of a heater including nine multiple flexible cable conductors positioned between tubulars.

[0132] FIG. 106 depicts a cross-sectional representation of an embodiment of a heater including nine multiple flexible cable conductors positioned between tubulars with spacers.

[0133] FIG. 107 depicts representation of an embodiment of a liner heater in a substantially horizontal wellbore used for producing hydrocarbons from a hydrocarbon layer.

[0134] FIG. 108 depicts a cross-sectional representation of an embodiment of a conductor with a core of a lead-in section spliced to a core of the remainder of the conductor.

[0135] FIG. 109 depicts an embodiment of a wellhead.

[0136] FIG. 110 depicts an example of a plot of dielectric constant versus temperature for magnesium oxide insulation in one embodiment of an insulated conductor heater.

[0137] FIG. 111 depicts an example of a plot of loss tangent (tan δ) versus temperature for magnesium oxide insulation in one embodiment of an insulated conductor heater.

[0138] FIG. 112 depicts an example of a plot of leakage current (mA) versus temperature (°F) for magnesium oxide insulation in one embodiment of an insulated conductor heater at different applied voltages.

[0139] FIG. 113 depicts an embodiment of an insulated conductor with salt used as electrical insulator.

[0140] FIG. 114 depicts an embodiment of an insulated conductor located proximate heaters in a wellbore.

[0141] FIG. 115 depicts an embodiment of an insulated conductor with voltage applied to the core and the jacket of the insulated conductor.

[0142] FIG. 116 depicts an embodiment of an insulated conductor with multiple hot spots.

[0143] FIG. 117 depicts a side view representation of an embodiment for producing mobilized fluids from a tar sands formation with a relatively thin hydrocarbon layer.

[0144] FIG. 118 depicts a side view representation of an embodiment for producing mobilized fluids from a tar sands formation with a hydrocarbon layer that is thicker than the hydrocarbon layer depicted in FIG. 117.

[0145] FIG. 119 depicts a side view representation of an embodiment for producing mobilized fluids from a tar sands formation with a hydrocarbon layer that is thicker than the hydrocarbon layer depicted in FIG. 118.

[0146] FIG. 120 depicts a side view representation of an embodiment for producing mobilized fluids from a tar sands formation with a hydrocarbon layer that has a shale break.

[0147] FIG. 121 is a representation of an embodiment of production of hydrocarbons and subsequent treating of a hydrocarbon formation to produce formation fluid.

[0148] FIG. 122 is a representation of an embodiment the use of a situ deasphalting fluid in treating a hydrocarbon formation.

[0149] FIG. 123 depicts a top view representation of an embodiment for preheating using heaters for a drive process.

[0150] FIG. 124 depicts a perspective representation of an embodiment for preheating using heaters for a drive process.

[0151] FIG. 125 depicts a side view representation of an embodiment of a tar sands formation subsequent to a steam injection process.

[0152] FIG. 126 depicts a side view representation of an embodiment using at least three treatment sections in a tar sands formation.

[0153] FIG. 127 depicts an embodiment for treating a formation with heaters in combination with one or more steam drive processes.

[0154] FIG. 128 depicts a comparison treating the formation using the embodiment depicted in FIG. 127 and treating the formation using the SAGD process.

[0155] FIG. 129 depicts an embodiment for heating and producing from a formation with a temperature limited heater in a production wellbore.

[0156] FIG. 130 depicts an embodiment for heating and producing from a formation with a temperature limited heater and a production wellbore.

[0157] FIG. 131 depicts a schematic of an embodiment of a first stage of treating a tar sands formation with electrical heaters.

[0158] FIG. 132 depicts a schematic of an embodiment of a second stage of treating the tar sands formation with fluid injection and oxidation.

[0159] FIG. 133 depicts a schematic of an embodiment of a third stage of treating the tar sands formation with fluid injection and oxidation.

[0160] FIG. 134 depicts a side view representation of a first stage of an embodiment of treating portions in a subsurface formation with heating, oxidation, and/or fluid injection.

[0161] FIG. 135 depicts a side view representation of a second stage of an embodiment of treating portions in the subsurface formation with heating, oxidation, and/or fluid injection.

[0162] FIG. 136 depicts a side view representation of a third stage of an embodiment of treating portions in subsurface formation with heating, oxidation and/or fluid injection.

[0163] FIG. 137 depicts an embodiment of treating a subsurface formation using a cylindrical pattern.

[0164] FIG. 138 depicts an embodiment of treating multiple portions of a subsurface formation in a rectangular pattern.

[0165] FIG. 139 is a schematic top view of the pattern depicted in FIG. 138.

[0166] FIG. 140 depicts a side view representation of an embodiments of treating a tar sands formation after treatment of the formation.

[0167] FIG. 141 depicts side view representation of another embodiment of treating a tar sands formation after treatment of the formation.

[0168] FIG. 142 depicts a top view representation of an embodiment of treatment of a hydrocarbon containing formation using an in situ heat treatment process.

[0169] FIG. 143 depicts a top view representation of another embodiment of treatment of a hydrocarbon containing formation using an in situ heat treatment process.

[0170] FIG. 144 depicts a cross-sectional representation of an embodiment of substantially horizontal heaters positioned in a pattern with consistent spacing in a hydrocarbon layer.

[0171] FIG. 145 depicts a cross-sectional representation of an embodiment of substantially horizontal heaters positioned in a pattern with irregular spacing in a hydrocarbon layer.

[0172] FIG. 146 depicts a graphical representation of a comparison of the temperature and the pressure over time for two different portions of the formation using the different heating patterns.

[0173] FIG. 147 depicts a graphical representation of a comparison of the average temperature over time for different treatment areas for two different portions of the formation using the different heating patterns.

[0174] FIG. 148 depicts a graphical representation of the bottom-hole pressures for several producer wells for two different heating patterns.

[0175] FIG. 149 depicts a graphical representation of a comparison of the cumulative oil and gas products extracted over time from two different portions of the formation using the different heating patterns.

[0176] FIG. 150 depicts a cross-sectional representation of another embodiment of substantially horizontal heaters positioned in a pattern with irregular spacing in a hydrocarbon layer.

[0177] FIG. 151 depicts a cross-sectional representation of another embodiment of substantially horizontal heaters positioned in a pattern with irregular spacing in a hydrocarbon layer.

[0178] FIG. 152 depicts a cross-sectional representation of another additional embodiment of substantially horizontal heaters positioned in a pattern with irregular spacing in a hydrocarbon layer.

[0179] FIG. 153 depicts a cross-sectional representation of another embodiment of substantially horizontal heaters positioned in a pattern with consistent spacing in a hydrocarbon layer.

[0180] FIG. 154 depicts a cross-sectional representation of an embodiment of substantially horizontal heaters positioned in a pattern with irregular spacing in a hydrocarbon layer, with three rows of heaters in three heating zones.

[0181] FIG. 155 depicts a schematic representation of an embodiment of a system for producing oxygen for use in downhole oxidizer assemblies.

[0182] FIG. 156 depicts an embodiment of a heater with a heating section located in a u-shaped wellbore to create a first heated volume.

[0183] FIG. 157 depicts an embodiment of a heater with a heating section located in a u-shaped wellbore to create a second heated volume.

[0184] FIG. 158 depicts an embodiment of a heater with a heating section located in a u-shaped wellbore to create a third heated volume.

[0185] FIG. 159 depicts an embodiment of a heater with a heating section located in an L-shaped or J-shaped wellbore to create a first heated volume.

[0186] FIG. 160 depicts an embodiment of a heater with a heating section located in an L-shaped or J-shaped wellbore to create a second heated volume.

[0187] FIG. 161 depicts an embodiment of a heater with a heating section located in an L-shaped or J-shaped wellbore to create a third heated volume.

[0188] FIG. 162 depicts an embodiment of two heaters with heating sections located in a u-shaped wellbore to create two heated volumes.

[0189] FIG. 163 depicts a top view of a treatment area treated using non-overlapping heating sections in heaters.

[0190] FIG. 164 depicts a top view of a treatment area treated using overlapping heating sections in the first phase of heating using heaters.

[0191] FIG. 165 depicts a schematic representation of an embodiment of a heat transfer fluid circulation system for heating a portion of a formation.

[0192] FIG. 166A depicts a schematic representation of an embodiment of an L-shaped heater for use with a heat transfer fluid circulation system for heating a portion of a formation.

[0193] FIG. 166B depicts a schematic representation of an embodiment of an L-shaped heater with a liner for use with a heat transfer fluid circulation system for heating a portion of a formation.

[0194] FIG. 167 depicts a schematic representation of an embodiment of a vertical heater for use with a heat transfer fluid circulation system for heating a portion of a formation where thermal expansion of the heater is accommodated below the surface.

[0195] FIG. 168 depicts a schematic representation of another embodiment of a vertical heater for use with a heat transfer fluid circulation system for heating a portion of a formation where thermal expansion of the heater is accommodated above and below the surface.

[0196] FIG. 169 depicts a schematic representation of a corridor pattern system used to treat a treatment area.

[0197] FIG. 170 depicts a schematic representation of a radial pattern system used to treat a treatment area.

[0198] FIG. 171 depicts a plan view of an embodiment of wellbore openings on a first side of a treatment area.

[0199] FIG. 172 depicts a cross-sectional view of an embodiment of overburden insulation that utilizes insulating cement.

[0200] FIG. 173 depicts a cross-sectional view of an embodiment of overburden insulation that utilizes an insulating sleeve.

[0201] FIG. 174 depicts a cross-sectional view of an embodiment of overburden insulation that utilizes an insulating sleeve and a vacuum.

[0202] FIG. 175 depicts a representation of an embodiment of bellows used to accommodate thermal expansion.

[0203] FIG. 176A depicts a representation of an embodiment of piping with an expansion loop for accommodating thermal expansion.

[0204] FIG. 176B depicts a representation of an embodiment of piping with coiled or spooled piping for accommodating thermal expansion.

[0205] FIG. 176C depicts a representation of an embodiment of piping with coiled or spooled piping for accommodating thermal expansion enclosed in an insulated volume.

[0206] FIG. 177 depicts a representation of an embodiment of insulated piping in a large diameter casing in the overburden.

[0207] FIG. 178 depicts a representation of an embodiment of insulated piping in a large diameter casing in the overburden to accommodate thermal expansion.

[0208] FIG. 179 depicts a representation of an embodiment of a wellhead with a sliding seal, stuffing box, or other pressure control equipment that allows a portion of a heater to move relative to the wellhead.

[0209] FIG. 180 depicts a representation of an embodiment of a wellhead with a slip joint that interacts with a fixed conduit above the wellhead.

[0210] FIG. 181 depicts a representation of an embodiment of a wellhead with a slip joint that interacts with a fixed conduit coupled to the wellhead.

[0211] FIG. 182 depicts a schematic representation of an embodiment of a heat transfer fluid circulating system with seals.

[0212] FIG. 183 depicts a schematic representation of another embodiment of a heat transfer fluid circulating system with seals.

[0213] FIG. 184 depicts a schematic representation of an embodiment of a heat transfer fluid circulating system with locking mechanisms and seals.

[0214] FIG. 185 depicts a representation of a u-shaped wellbore with a hot heat transfer fluid circulation system heater positioned in the wellbore.

[0215] FIG. 186 depicts a side view representation of an embodiment of a system for heating the formation that can use a closed loop circulation system and/or electrical heating.

[0216] FIG. 187 depicts a representation of a heat transfer fluid conduit that may initially be resistively heated with the return current path provided by an insulated conductor.

[0217] FIG. 188 depicts a representation of a heat transfer fluid conduit that may initially be resistively heated with the return current path provided by two insulated conductors.

[0218] FIG. 189 depicts a representation of insulated conductors used to resistively heat heaters of a circulated fluid heating system.

[0219] FIG. 190 depicts an end view representation of a heater of a heat transfer fluid circulation system with an insulated conductor heater positioned in the piping.

[0220] FIG. 191 depicts an end view representation of an embodiment of a conduit-in-conduit heater for a heat transfer circulation heating system adjacent to the treatment area.

[0221] FIG. 192 depicts a representation of an embodiment for heating various portions of a heater to restart flow of heat transfer fluid in the heater.

[0222] FIG. 193 depicts a schematic of an embodiment of conduit-in-conduit heaters of a fluid circulation heating system positioned in the formation.

[0223] FIG. 194 depicts a cross-sectional view of an embodiment of a conduit-in-conduit heater adjacent to the overburden.

[0224] FIG. 195 depicts a schematic representation of an embodiment of a circulation system for a liquid heat transfer fluid.

[0225] FIG. 196 depicts a schematic representation of an embodiment of a system for heating the formation using gas lift to return the heat transfer fluid to the surface.

[0226] FIG. 197 depicts a schematic representation of an embodiment of a vertical conduit-in-conduit heater for use with a heat transfer fluid circulation system for heating a portion of a formation.

[0227] FIG. 198 depicts a graphical representation of the relationship of the electrical resistance of an inner conduit of a conduit-in-conduit heater over a depth at which a breach has occurred in the inner conduit of the conduit-in-conduit heater.

[0228] FIG. 199 depicts a graphical representation of the relationship of the electrical resistance of an outer conduit of a conduit-in-conduit heater over a depth at which a breach has occurred in the outer conduit of the conduit-in-conduit heater.

[0229] FIG. 200 depicts a graphical representation of the relationship of the electrical resistance of an inner conduit of a conduit-in-conduit heater and the salt block height over an amount of leaked molten salt.

[0230] FIG. 201 depicts a graphical representation of the relationship of the electrical resistance of an outer conduit of a conduit-in-conduit heater and the salt block height over an amount of leaked molten salt.

[0231] FIG. 202 depicts a graphical representation of the relationship of the electrical resistance of a conduit of a conduit-in-conduit heater once a breach forms over an average temperature of the molten salt.

[0232] FIG. 203 depicts a schematic representation of an embodiment of a vertical heater for use with a heat transfer fluid circulation system for heating a portion of a formation including an inert gas based leak detection system.

[0233] FIG. 204 depicts a graphical representation of the relationship of the salt displacement efficiency over time for three different compressed air mass flow rates.

[0234] FIG. 205 depicts a graphical representation of the relationship of the air volume flow rate at inlet of a conduit over time for three different compressed air mass flow rates.

[0235] FIG. 206 depicts a graphical representation of the relationship of the compressor discharge pressure over time for three different compressed air mass flow rates.

[0236] FIG. 207 depicts a graphical representation of the relationship of the salt volume fraction at outlet of a conduit over time for three different compressed air mass flow rates.

[0237] FIG. 208 depicts a graphical representation of the relationship of the salt volume flow rate at outlet of a conduit over time for three different compressed air mass flow rates.

[0238] FIG. 209 depicts a schematic representation of an embodiment of a compressed air shut-down system.

[0239] FIG. 210 depicts an end view representation of an embodiment of a wellbore in a treatment area undergoing a combustion process.

[0240] FIG. 211 depicts an end view representation of an embodiment of a wellbore in a treatment area undergoing fluid removal following the combustion process.

[0241] FIG. 212 depicts an end view representation of an embodiment of a wellbore in a treatment area undergoing a combustion process using circulated molten salt to recover energy from the treatment area.

[0242] FIG. 213 depicts a percentage of the expected coke distribution relative to a distance from a wellbore.

[0243] FIG. 214 depicts a schematic representation of an embodiment of an in situ heat treatment system that uses a nuclear reactor.

[0244] FIG. 215 depicts an elevational view of an embodiment of an in situ heat treatment system using pebble bed reactors.

[0245] FIG. 216 depicts a schematic representation of an embodiment of a self-regulating nuclear reactor.

[0246] FIG. 217 depicts a schematic representation of an embodiment of an in situ heat treatment system with u-shaped wellbores using self-regulating nuclear reactors.

[0247] FIG. 218 depicts a schematic representation of a system for heating a formation using carbonate molten salt.

[0248] FIG. 219 depicts a schematic representation of a system after heating a formation using carbonate molten salt.

[0249] FIG. 220 depicts a cross-sectional representation of an embodiment of a section of the formation after heating the formation with a carbonate molten salt.

[0250] FIGS. 221A and 221B depict representations of an embodiment of heating a hydrocarbon containing formation in stages.

[0251] FIG. 222 is a representation of an embodiment of treating hydrocarbon formations containing sulfur and/or inorganic nitrogen compounds.

[0252] FIG. 223 depicts a representation of an embodiment of treating hydrocarbon formations containing inorganic compounds using selected heating.

[0253] FIG. 224 depicts a representation of an embodiment of treating hydrocarbon formation using an in situ heat treatment process with subsurface removal of mercury from formation fluid.

[0254] FIG. 225 depicts a side view representation of an embodiment for producing mobilized fluids from a hydrocarbon formation.

[0255] FIG. 226 depicts a side view representation of an embodiment for producing mobilized fluids from a hydrocarbon formation heated by residual heat.

[0256] FIG. 227 depicts an embodiment of a solution mining well.

[0257] FIG. 228 depicts a representation of an embodiment of a portion of a solution mining well.

[0258] FIG. 229 depicts a representation of another embodiment of a portion of a solution mining well.

[0259] FIG. 230 depicts an elevational view of a well pattern for solution mining and/or an in situ heat treatment process.

[0260] FIG. 231 depicts a representation of wells of an in situ heating treatment process for solution mining and producing hydrocarbons from a formation.

[0261] FIG. 232 depicts an embodiment for solution mining a formation.

[0262] FIG. 233 depicts an embodiment of a formation with nahcolite layers in the formation before solution mining nahcolite from the formation.

[0263] FIG. 234 depicts the formation of FIG. 233 after the nahcolite has been solution mined.

[0264] FIG. 235 depicts an embodiment of two injection wells interconnected by a zone that has been solution mined to remove nahcolite from the zone.

[0265] FIG. 236 depicts a representation of an embodiment for treating a portion of a formation having a hydrocarbon containing formation between an upper nahcolite bed and a lower nahcolite bed.

[0266] FIG. 237 depicts a representation of a portion of the formation that is orthogonal to the formation depicted in FIG. 236 and passes through one of the solution mining wells in the upper nahcolite bed.

[0267] FIG. 238 depicts an embodiment for heating a formation with dawsonite in the formation.

[0268] FIG. 239 depicts a representation of an embodiment for solution mining with a steam and electricity cogeneration facility.

[0269] FIG. 240 depicts an embodiment of treating a hydrocarbon containing formation with a combustion front.

[0270] FIG. 241 depicts a cross-sectional representation of an embodiment for treating a hydrocarbon containing formation with a combustion front.

[0271] FIG. 242 depicts a schematic of an embodiment for treating a subsurface formation using heat sources having electrically conductive material.

[0272] FIG. 243 depicts a schematic of an embodiment for treating a subsurface formation using a ground and heat sources having electrically conductive material.

[0273] FIG. 244 depicts a schematic of an embodiment for treating a subsurface formation using heat sources having electrically conductive material and an electrical insulator.

[0274] FIG. 245 depicts a schematic of an embodiment for treating a subsurface formation using electrically conductive heat sources extending from a common wellbore.

[0275] FIG. 246 depicts an embodiment of a conduit with heating zone cladding and a conductor with overburden cladding.

[0276] FIG. 247 depicts a schematic of an embodiment for treating a subsurface formation having a shale layer using heat sources having electrically conductive material.

[0277] FIG. 248A depicts a schematic of an embodiment of an electrode with a coated end.

[0278] FIG. 248B depicts a schematic of an embodiment of an uncoated electrode.

[0279] FIG. 249A depicts a schematic of another embodiment of a coated electrode.

[0280] FIG. 249B depicts a schematic of another embodiment of an uncoated electrode.

[0281] FIG. 250 depicts an embodiment of a u-shaped heater that has an inductively energized tubular.

[0282] FIG. 251 depicts an embodiment of an electrical conductor centralized inside a tubular.

[0283] FIG. 252 depicts an embodiment of an induction heater with a sheath of an insulated conductor in electrical contact with a tubular.

[0284] FIG. 253 depicts a perspective view of an embodiment of an underground treatment system.

[0285] FIG. 254 depicts an exploded perspective view of an embodiment of a portion of an underground treatment system and tunnels.

[0286] FIG. 255 depicts another exploded perspective view of an embodiment of a portion of an underground treatment system and tunnels.

[0287] FIG. 256 depicts a side view representation of an embodiment for flowing heated fluid through heat sources between tunnels.

[0288] FIG. 257 depicts a top view representation of an embodiment for flowing heated fluid through heat sources between tunnels.

[0289] FIG. 258 depicts a perspective view of an embodiment of an underground treatment system having heater wellbores spanning between tunnels of the underground treatment system.

[0290] FIG. 259 depicts a top view of an embodiment of tunnels with wellbore chambers.

[0291] FIG. 260 depicts a top view of an embodiment of development of a tunnel.

[0292] FIG. 261 depicts a schematic of an embodiment of an underground treatment system with surface production.

[0293] FIG. 262 depicts a side view of an embodiment of an underground treatment system.

[0294] FIG. 263 depicts the electric field normal component as a function of the location along the length of the heater.

[0295] FIG. 264 depicts the electric field strength versus distance from the core.

[0296] FIG. 265 depicts percent of maximum unscreened (no semiconductor layer) field strength and normalized semiconductor layer thickness versus dielectric constant ratio of the electrical insulator and semiconductor layer.

[0297] FIG. 266 depicts electric field strength versus normalized distance from the core for several dielectric constant ratios.

[0298] FIG. 267 depicts a temperature profile in the formation after 360 days using the STARS simulation.

[0299] FIG. 268 depicts an oil saturation profile in the formation after 360 days using the STARS simulation.

[0300] FIG. 269 depicts the oil saturation profile in the formation after 1095 days using the STARS simulation.

[0301] FIG. 270 depicts the oil saturation profile in the formation after 1470 days using the STARS simulation.

[0302] FIG. 271 depicts the oil saturation profile in the formation after 1826 days using the STARS simulation.

[0303] FIG. 272 depicts the temperature profile in the formation after 1826 days using the STARS simulation.

[0304] FIG. 273 depicts oil production rate and gas production rate versus time.

[0305] FIG. 274 depicts weight percentage of original bitumen in place (OBIP)(left axis) and volume percentage of OBIP (right axis) versus temperature (°C).

[0306] FIG. 275 depicts bitumen conversion percentage (weight percentage of (OBIP))(left axis) and oil, gas, and coke weight percentage (as a weight percentage of OBIP)(right axis) versus temperature (°C).

[0307] FIG. 276 depicts API gravity (°)(left axis) of produced fluids, blow down production, and oil left in place along with pressure (psig)(right axis) versus temperature (°C).

[0308] FIGS. 277A-D depict gas-to-oil ratios (GOR) in thousand cubic feet per barrel ((Mcf/bbl)(y-axis)) versus temperature (°C)(x-axis) for different types of gas at a low temperature blow down (about 277 °C) and a high temperature blow down (at about 290 °C).

[0309] FIG. 278 depicts coke yield (weight percentage)(y-axis) versus temperature (°C)(x-axis).

[0310] FIGS. 279A-D depict assessed hydrocarbon isomer shifts in fluids produced from the experimental cells as a function of temperature and bitumen conversion.

[0311] FIG. 280 depicts weight percentage (Wt%)(y-axis) of saturates from SARA analysis of the produced fluids versus temperature (°C)(x-axis).

[0312] FIG. 281 depicts weight percentage (Wt%)(y-axis) of n-C_7 of the produced fluids versus temperature (°C)(x-axis).

[0313] FIG. 282 depicts oil recovery (volume percentage bitumen in place (vol% BIP)) versus API gravity (°) as determined by the pressure (MPa) in the formation in an experiment.

[0314] FIG. 283 depicts recovery efficiency (%) versus temperature (°C) at different pressures in an experiment.

[0315] FIG. 284 depicts average formation temperature (°C) versus days for heating a formation using molten salt circulated through conduit-in-conduit heaters.

[0316] FIG. 285 depicts molten salt temperature (°C) and power injection rate (W/ft) versus time (days).

[0317] FIG. 286 depicts temperature (°C) and power injection rate (W/ft) versus time (days) for heating a formation using molten salt circulated through heaters with a heating length of 8000 ft at a mass flow rate of 18 kg/s.

[0318] FIG. 287 depicts temperature (°C) and power injection rate (W/ft) versus time (days) for heating a formation using molten salt circulated through heaters with a heating length of 8000 ft at a mass flow rate of 12 kg/s.

[0319] FIG. 288 depicts power (W/ft)(y-axis) versus time (yr)(x-axis) of in situ heat treatment power injection requirements.

[0320] FIG. 289 depicts power (W/ft)(y-axis) versus time (days)(x-axis) of in situ heat treatment power injection requirements for different spacings between wellbores.

[0321] FIG. 290 depicts reservoir average temperature (°C)(y-axis) versus time (days)(x-axis) of in situ heat treatment for different spacings between wellbores.

[0322] FIG. 291 depicts time (hour) versus temperature (°C) and molten salt concentration in weight percent.

[0323] FIG. 292 depicts heat transfer rates versus time.

[0324] FIG. 293 is a graphical representation of asphaltene H/C molar ratios of hydrocarbons having a boiling point greater than 520 °C versus time (days).

[0325] FIG. 294 depicts percentage of degree of saturation (volume water/air voids) versus time during immersion at a water temperature of 60 °C.

[0326] FIG. 295 depicts retained indirect tensile strength stiffness modulus versus time during immersion at a water temperature of 60 °C.

[0327] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and may herein be described in detail. The drawings may not be to scale. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION

[0328] The following description generally relates to systems and methods for treating hydrocarbons in the formations. Such formations may be treated to yield hydrocarbon products, hydrogen, and other products.

[0329] "Alternating current (AC)" refers to a time-varying current that reverses direction substantially sinusoidally. AC produces skin effect electricity flow in a ferromagnetic conductor.

[0330] "Annular region" is the region between an outer conduit and an inner conduit positioned in the outer conduit.

[0331] "API gravity" refers to API gravity at 15.5 °C (60 °F). API gravity is as determined by ASTM Method D6822 or ASTM Method D1298.

[0332] "ASTM" refers to American Standard Testing and Materials.

[0333] In the context of reduced heat output heating systems, apparatus, and methods, the term "automatically" means such systems, apparatus, and methods function in a certain way without the use of external control (for example, external controllers such as a controller with a temperature sensor and a feedback loop, PID controller, or predictive controller).

[0334] "Asphalt/bitumen" refers to a semi-solid, viscous material soluble in carbon disulfide. Asphalt/bitumen may be obtained from refining operations or produced from subsurface formations.

[0335] "Bare metal" and "exposed metal" refer to metals of elongated members that do not include a layer of electrical insulation, such as mineral insulation, that is designed to provide electrical insulation for the metal throughout an operating temperature range of the elongated member. Bare metal and exposed metal may encompass a metal that includes a corrosion inhibiter such as a naturally occurring oxidation layer, an applied oxidation layer, and/or a film. Bare metal and exposed metal include metals with polymeric or other types of electrical insulation that cannot retain electrical insulating properties at typical operating temperature of the elongated member. Such material may be placed on the metal and may be thermally degraded during use of the heater.

[0336] Boiling range distributions for the formation fluid and liquid streams described herein are as determined by ASTM Method D5307 or ASTM Method D2887. Content of hydrocarbon components in weight percent for paraffins, iso-paraffins, olefins, naphthenes and aromatics in the liquid streams is as determined by ASTM Method D6730. Content of aromatics in volume percent is as determined by ASTM Method D1319. Weight percent of hydrogen in hydrocarbons is as determined by ASTM Method D3343.

[0337] "Bromine number" refers to a weight percentage of olefins in grams per 100 gram of portion of the produced fluid that has a boiling range below 246 °C and testing the portion using ASTM Method D1159.

[0338] "Carbon number" refers to the number of carbon atoms in a molecule. A hydrocarbon fluid may include various hydrocarbons with different carbon numbers. The hydrocarbon fluid may be described by a carbon number distribution. Carbon numbers and/or carbon number distributions may be determined by true boiling point distribution and/or gas-liquid chromatography.

[0339] "Chemical stability" refers to the ability of a formation fluid to be transported without components in the formation fluid reacting to form polymers and/or compositions that plug pipelines, valves, and/or vessels.

[0340] "Clogging" refers to impeding and/or inhibiting flow of one or more compositions through a process vessel or a conduit.

[0341] "Column X element" or "Column X elements" refer to one or more elements of Column X of the Periodic Table, and/or one or more compounds of one or more elements of Column X of the Periodic Table, in which X corresponds to a column number (for example, 13-18) of the Periodic Table. For example, "Column 15 elements" refer to elements from Column 15 of the Periodic Table and/or compounds of one or more elements from Column 15 of the Periodic Table.

[0342] "Column X metal" or "Column X metals" refer to one or more metals of Column X of the Periodic Table and/or one or more compounds of one or more metals of Column X of the Periodic Table, in which X corresponds to a column number (for example, 1-12) of the Periodic Table. For example, "Column 6 metals" refer to metals from Column 6 of the Periodic Table and/or compounds of one or more metals from Column 6 of the Periodic Table.

[0343] "Condensable hydrocarbons" are hydrocarbons that condense at 25 °C and one atmosphere absolute pressure. Condensable hydrocarbons may include a mixture of hydrocarbons having carbon numbers greater than 4. "Non-condensable hydrocarbons" are hydrocarbons that do not condense at 25 °C and one atmosphere absolute pressure. Non-condensable hydrocarbons may include hydrocarbons having carbon numbers less than 5.

[0344] "Coring" is a process that generally includes drilling a hole into a formation and removing a substantially solid mass of the formation from the hole.

[0345] "Coupled" means either a direct connection or an indirect connection (for example, one or more intervening connections) between one or more objects or components. The phrase "directly connected" means a direct connection between objects or components such that the objects or components are connected directly to each other so that the objects or components operate in a "point of use" manner.

[0346] "Cracking" refers to a process involving decomposition and molecular recombination of organic compounds to produce a greater number of molecules than were initially present. In cracking, a series of reactions take place accompanied by a transfer of hydrogen atoms between molecules. For example, naphtha may undergo a thermal cracking reaction to form ethene and H_2.

[0347] "Curie temperature" is the temperature above which a ferromagnetic material loses all of its ferromagnetic properties. In addition to losing all of its ferromagnetic properties above the

Curie temperature, the ferromagnetic material begins to lose its ferromagnetic properties when an increasing electrical current is passed through the ferromagnetic material.

[0348] "Diad" refers to a group of two items (for example, heaters, wellbores, or other objects) coupled together.

[0349] "Diesel" refers to hydrocarbons with a boiling range distribution between 260 °C and 343 °C (500-650 °F) at 0.101 MPa. Diesel content is determined by ASTM Method D2887.

[0350] "Enriched air" refers to air having a larger mole fraction of oxygen than air in the atmosphere. Air is typically enriched to increase combustion-supporting ability of the air.

[0351] A "fluid" may be, but is not limited to, a gas, a liquid, an emulsion, a slurry, and/or a stream of solid particles that has flow characteristics similar to liquid flow.

[0352] "Fluid injectivity" is the flow rate of fluids injected per unit of pressure differential between a first location and a second location.

[0353] "Fluid pressure" is a pressure generated by a fluid in a formation. "Lithostatic pressure" (sometimes referred to as "lithostatic stress") is a pressure in a formation equal to a weight per unit area of an overlying rock mass. "Hydrostatic pressure" is a pressure in a formation exerted by a column of water.

[0354] A "formation" includes one or more hydrocarbon containing layers, one or more non-hydrocarbon layers, an overburden, and/or an underburden. "Hydrocarbon layers" refer to layers in the formation that contain hydrocarbons. The hydrocarbon layers may contain non-hydrocarbon material and hydrocarbon material. The "overburden" and/or the "underburden" include one or more different types of impermeable materials. For example, the overburden and/or underburden may include rock, shale, mudstone, or wet/tight carbonate. In some embodiments of in situ heat treatment processes, the overburden and/or the underburden may include a hydrocarbon containing layer or hydrocarbon containing layers that are relatively impermeable and are not subjected to temperatures during in situ heat treatment processing that result in significant characteristic changes of the hydrocarbon containing layers of the overburden and/or the underburden. For example, the underburden may contain shale or mudstone, but the underburden is not allowed to heat to pyrolysis temperatures during the in situ heat treatment process. In some cases, the overburden and/or the underburden may be somewhat permeable.

[0355] "Formation fluids" refer to fluids present in a formation and may include pyrolyzation fluid, synthesis gas, mobilized hydrocarbons, and water (steam). Formation fluids may include hydrocarbon fluids as well as non-hydrocarbon fluids. The term "mobilized fluid" refers to fluids in a hydrocarbon containing formation that are able to flow as a result of thermal treatment of the formation. "Produced fluids" refer to fluids removed from the formation.

[0356] "Freezing point" of a hydrocarbon liquid refers to the temperature below which solid hydrocarbon crystals may form in the liquid. Freezing point is as determined by ASTM Method D5901.

[0357] "Heat flux" is a flow of energy per unit of area per unit of time (for example, Watts/meter^2).

[0358] A "heat source" is any system for providing heat to at least a portion of a formation substantially by conductive and/or radiative heat transfer. For example, a heat source may include electrically conducting materials and/or electric heaters such as an insulated conductor, an elongated member, and/or a conductor disposed in a conduit. A heat source may also include systems that generate heat by burning a fuel external to or in a formation. The systems may be surface burners, downhole gas burners, flameless distributed combustors, and natural distributed combustors. In some embodiments, heat provided to or generated in one or more heat sources may be supplied by other sources of energy. The other sources of energy may directly heat a formation, or the energy may be applied to a transfer medium that directly or indirectly heats the formation. It is to be understood that one or more heat sources that are applying heat to a formation may use different sources of energy. Thus, for example, for a given formation some heat sources may supply heat from electrically conducting materials, electric resistance heaters, some heat sources may provide heat from combustion, and some heat sources may provide heat from one or more other energy sources (for example, chemical reactions, solar energy, wind energy, biomass, or other sources of renewable energy). A chemical reaction may include an exothermic reaction (for example, an oxidation reaction). A heat source may also include a electrically conducting material and/or a heater that provides heat to a zone proximate and/or surrounding a heating location such as a heater well.

[0359] A "heater" is any system or heat source for generating heat in a well or a near wellbore region. Heaters may be, but are not limited to, electric heaters, burners, combustors that react with material in or produced from a formation, and/or combinations thereof.

[0360] "Heavy hydrocarbons" are viscous hydrocarbon fluids. Heavy hydrocarbons may include highly viscous hydrocarbon fluids such as heavy oil, tar, and/or asphalt. Heavy hydrocarbons may include carbon and hydrogen, as well as smaller concentrations of sulfur, oxygen, and nitrogen. Additional elements may also be present in heavy hydrocarbons in trace amounts. Heavy hydrocarbons may be classified by API gravity. Heavy hydrocarbons generally have an API gravity below about 20°. Heavy oil, for example, generally has an API gravity of about 10-20°, whereas tar generally has an API gravity below about 10°. The viscosity of heavy hydrocarbons is generally greater than about 100 centipoise at 15 °C. Heavy hydrocarbons may include aromatics or other complex ring hydrocarbons.

[0361] Heavy hydrocarbons may be found in a relatively permeable formation. The relatively permeable formation may include heavy hydrocarbons entrained in, for example, sand or carbonate. "Relatively permeable" is defined, with respect to formations or portions thereof, as an average permeability of 10 millidarcy or more (for example, 10 or 100 millidarcy). "Relatively low permeability" is defined, with respect to formations or portions thereof, as an average permeability of less than about 10 millidarcy. One darcy is equal to about 0.99 square micrometers. An impermeable layer generally has a permeability of less than about 0.1 millidarcy.

[0362] Certain types of formations that include heavy hydrocarbons may also include, but are not limited to, natural mineral waxes, or natural asphaltites. "Natural mineral waxes" typically occur in substantially tubular veins that may be several meters wide, several kilometers long, and hundreds of meters deep. "Natural asphaltites" include solid hydrocarbons of an aromatic composition and typically occur in large veins. In situ recovery of hydrocarbons from formations such as natural mineral waxes and natural asphaltites may include melting to form liquid hydrocarbons and/or solution mining of hydrocarbons from the formations.

[0363] "Hydrocarbons" are generally defined as molecules formed primarily by carbon and hydrogen atoms. Hydrocarbons may also include other elements such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur. Hydrocarbons may be, but are not limited to, kerogen, bitumen, pyrobitumen, oils, natural mineral waxes, and asphaltites. Hydrocarbons may be located in or adjacent to mineral matrices in the earth. Matrices may include, but are not limited to, sedimentary rock, sands, silicilytes, carbonates, diatomites, and other porous media. "Hydrocarbon fluids" are fluids that include hydrocarbons. Hydrocarbon fluids may include, entrain, or be entrained in non-hydrocarbon fluids such as hydrogen, nitrogen, carbon monoxide, carbon dioxide, hydrogen sulfide, water, and ammonia.

[0364] An "in situ conversion process" refers to a process of heating a hydrocarbon containing formation from heat sources to raise the temperature of at least a portion of the formation above a pyrolysis temperature so that pyrolyzation fluid is produced in the formation.

[0365] An "in situ heat treatment process" refers to a process of heating a hydrocarbon containing formation with heat sources to raise the temperature of at least a portion of the formation above a temperature that results in mobilized fluid, visbreaking, and/or pyrolysis of hydrocarbon containing material so that mobilized fluids, visbroken fluids, and/or pyrolyzation fluids are produced in the formation.

[0366] "Insulated conductor" refers to any elongated material that is able to conduct electricity and that is covered, in whole or in part, by an electrically insulating material.

[0367] "Karst" is a subsurface shaped by the dissolution of a soluble layer or layers of bedrock, usually carbonate rock such as limestone or dolomite. The dissolution may be caused by meteoric or acidic water. The Grosmont formation in Alberta, Canada is an example of a karst (or "karsted") carbonate formation.

[0368] "Kerogen" is a solid, insoluble hydrocarbon that has been converted by natural degradation and that principally contains carbon, hydrogen, nitrogen, oxygen, and sulfur. Coal and oil shale are typical examples of materials that contain kerogen. "Bitumen" is a non-crystalline solid or viscous hydrocarbon material that is substantially soluble in carbon disulfide. "Oil" is a fluid containing a mixture of condensable hydrocarbons.

[0369] "Kerosene" refers to hydrocarbons with a boiling range distribution between 204 °C and 260 °C at 0.101 MPa. Kerosene content is determined by ASTM Method D2887.

[0370] "Modulated direct current (DC)" refers to any substantially non-sinusoidal time-varying current that produces skin effect electricity flow in a ferromagnetic conductor.

[0371] "Naphtha" refers to hydrocarbon components with a boiling range distribution between 38 °C and 200 °C at 0.101 MPa. Naphtha content is determined by ASTM Method D5307.

[0372] "Nitride" refers to a compound of nitrogen and one or more other elements of the Periodic Table. Nitrides include, but are not limited to, silicon nitride, boron nitride, or alumina nitride.

[0373] "Nitrogen compounds" refer to inorganic and organic compounds containing the element nitrogen. Examples of nitrogen compounds include, but are not limited to, ammonia and organonitrogen compounds. "Organonitrogen compounds" refer to hydrocarbons that contain at least one nitrogen atom. Non-limiting examples of organonitrogen compounds include, but are not limited to, amines, alkyl amines, aromatic amines, alkyl amides, aromatic amides, carbozoles, hydrogenated carbazoles, indoles pyridines, pyrazoles, pyrroles,and oxazoles.

[0374] "Nitrogen compound content" refers to an amount of nitrogen in an organic compound. Nitrogen content is as determined by ASTM Method D5762.

[0375] "Octane Number" refers to a calculated numerical representation of the antiknock properties of a motor fuel compared to a standard reference fuel. A calculated octane number is determined by ASTM Method D6730.

[0376] "Olefins" are molecules that include unsaturated hydrocarbons having one or more non-aromatic carbon-carbon double bonds.

[0377] "Olefin content" refers to an amount of non-aromatic olefins in a fluid. Olefin content for a produced fluid is determined by obtaining a portion of the produce fluid that has a boiling point of 246 °C and testing the portion using ASTM Method D1159 and reporting the result as a bromine factor in grams per 100 gram of portion. Olefin content is also determined by the

Canadian Association of Petroleum Producers (CAPP) olefin method and is reported in percent olefin as 1-decene equivalent.

[0378] "Orifices" refer to openings, such as openings in conduits, having a wide variety of sizes and cross-sectional shapes including, but not limited to, circles, ovals, squares, rectangles, triangles, slits, or other regular or irregular shapes.

[0379] "Oxygen containing compounds" refer to compounds containing the element oxygen. Examples of compounds containing oxygen include, but are not limited to, phenols, and/or carbon dioxide.

[0380] "P (peptization) value" or "P-value" refers to a numerical value, which represents the flocculation tendency of asphaltenes in a formation fluid. P-value is determined by ASTM method D7060.

[0381] "Perforations" include openings, slits, apertures, or holes in a wall of a conduit, tubular, pipe or other flow pathway that allow flow into or out of the conduit, tubular, pipe or other flow pathway.

[0382] "Periodic Table" refers to the Periodic Table as specified by the International Union of Pure and Applied Chemistry (IUPAC), November 2003. In the scope of this application, weight of a metal from the Periodic Table, weight of a compound of a metal from the Periodic Table, weight of an element from the Periodic Table, or weight of a compound of an element from the Periodic Table is calculated as the weight of metal or the weight of element. For example, if 0.1 grams of MoO_3 is used per gram of catalyst, the calculated weight of the molybdenum metal in the catalyst is 0.067 grams per gram of catalyst.

[0383] "Phase transformation temperature" of a ferromagnetic material refers to a temperature or a temperature range during which the material undergoes a phase change (for example, from ferrite to austenite) that decreases the magnetic permeability of the ferromagnetic material. The reduction in magnetic permeability is similar to reduction in magnetic permeability due to the magnetic transition of the ferromagnetic material at the Curie temperature.

[0384] "Physical stability" refers to the ability of a formation fluid to not exhibit phase separation or flocculation during transportation of the fluid. Physical stability is determined by ASTM Method D7060.

[0385] "Pyrolysis" is the breaking of chemical bonds due to the application of heat. For example, pyrolysis may include transforming a compound into one or more other substances by heat alone. Heat may be transferred to a section of the formation to cause pyrolysis.

[0386] "Pyrolyzation fluids" or "pyrolysis products" refers to fluid produced substantially during pyrolysis of hydrocarbons. Fluid produced by pyrolysis reactions may mix with other fluids in a formation. The mixture would be considered pyrolyzation fluid or pyrolyzation product. As

used herein, "pyrolysis zone" refers to a volume of a formation (for example, a relatively permeable formation such as a tar sands formation) that is reacted or reacting to form a pyrolyzation fluid.

[0387] "Residue" refers to hydrocarbons that have a boiling point above 537 °C (1000 °F).

[0388] "Rich layers" in a hydrocarbon containing formation are relatively thin layers (typically about 0.2 m to about 0.5 m thick). Rich layers generally have a richness of about 0.150 L/kg or greater. Some rich layers have a richness of about 0.170 L/kg or greater, of about 0.190 L/kg or greater, or of about 0.210 L/kg or greater. Lean layers of the formation have a richness of about 0.100 L/kg or less and are generally thicker than rich layers. The richness and locations of layers are determined, for example, by coring and subsequent Fischer assay of the core, density or neutron logging, or other logging methods. Rich layers may have a lower initial thermal conductivity than other layers of the formation. Typically, rich layers have a thermal conductivity 1.5 times to 3 times lower than the thermal conductivity of lean layers. In addition, rich layers have a higher thermal expansion coefficient than lean layers of the formation.

[0389] "Smart well technology" or "smart wellbore" refers to wells that incorporate downhole measurement and/or control. For injection wells, smart well technology may allow for controlled injection of fluid into the formation in desired zones. For production wells, smart well technology may allow for controlled production of formation fluid from selected zones. Some wells may include smart well technology that allows for formation fluid production from selected zones and simultaneous or staggered solution injection into other zones. Smart well technology may include fiber optic systems and control valves in the wellbore. A smart wellbore used for an in situ heat treatment process may be Westbay Multilevel Well System MP55 available from Westbay Instruments Inc. (Burnaby, British Columbia, Canada).

[0390] "Subsidence" is a downward movement of a portion of a formation relative to an initial elevation of the surface.

[0391] "Sulfur containing compounds" refer to inorganic and organic sulfur compounds. Examples of inorganic sulfur compounds include, but are not limited to, hydrogen sulfide and/or iron sulfides. Examples of organic sulfur compounds (organosulfur compounds) include, but are not limited to, carbon disulfide, mercaptans, thiophenes, hydrogenated benzothiophenes, benzothiophenes, dibenzothiophenes, hydrogenated dibenzothiophenes or mixtures thereof.

[0392] "Sulfur compound content" refers to an amount of sulfur in an organic compound in hydrocarbons. Sulfur content is as determined by ASTM Method D4294. ASTM Method D4294 may be used to determine forms of sulfur in an oil shale sample. Forms of sulfur in an oil shale sample includes, but is not limited to, pyritic sulfur, sulfate sulfur, and organic sulfur. Total sulfur content in oil shale is determined by ASTM D4239.

[0393] "Superposition of heat" refers to providing heat from two or more heat sources to a selected section of a formation such that the temperature of the formation at least at one location between the heat sources is influenced by the heat sources.

[0394] "Synthesis gas" is a mixture including hydrogen and carbon monoxide. Additional components of synthesis gas may include water, carbon dioxide, nitrogen, methane, and other gases. Synthesis gas may be generated by a variety of processes and feedstocks. Synthesis gas may be used for synthesizing a wide range of compounds.

[0395] "TAN" refers to a total acid number expressed as milligrams ("mg") of KOH per gram ("g") of sample. TAN is as determined by ASTM Method D3242.

[0396] "Tar" is a viscous hydrocarbon that generally has a viscosity greater than about 10,000 centipoise at 15 °C. The specific gravity of tar generally is greater than 1.000. Tar may have an API gravity less than 10°.

[0397] A "tar sands formation" is a formation in which hydrocarbons are predominantly present in the form of heavy hydrocarbons and/or tar entrained in a mineral grain framework or other host lithology (for example, sand or carbonate). Examples of tar sands formations include formations such as the Athabasca formation, the Grosmont formation, and the Peace River formation, all three in Alberta, Canada; and the Faja formation in the Orinoco belt in Venezuela.

[0398] "Temperature limited heater" generally refers to a heater that regulates heat output (for example, reduces heat output) above a specified temperature without the use of external controls such as temperature controllers, power regulators, rectifiers, or other devices. Temperature limited heaters may be AC (alternating current) or modulated (for example, "chopped") DC (direct current) powered electrical resistance heaters.

[0399] "Thermally conductive fluid" includes fluid that has a higher thermal conductivity than air at standard temperature and pressure (STP) (0 °C and 101.325 kPa).

[0400] "Thermal conductivity" is a property of a material that describes the rate at which heat flows, in steady state, between two surfaces of the material for a given temperature difference between the two surfaces.

[0401] "Thermal fracture" refers to fractures created in a formation caused by expansion or contraction of a formation and/or fluids in the formation, which is in turn caused by increasing/decreasing the temperature of the formation and/or fluids in the formation, and/or by increasing/decreasing a pressure of fluids in the formation due to heating.

[0402] "Thermal oxidation stability" refers to thermal oxidation stability of a liquid. Thermal oxidation stability is as determined by ASTM Method D3241.

[0403] "Thickness" of a layer refers to the thickness of a cross section of the layer, wherein the cross section is normal to a face of the layer.

[0404] "Time-varying current" refers to electrical current that produces skin effect electricity flow in a ferromagnetic conductor and has a magnitude that varies with time. Time-varying current includes both alternating current (AC) and modulated direct current (DC).

[0405] "Triad" refers to a group of three items (for example, heaters, wellbores, or other objects) coupled together.

[0406] "Turndown ratio" for the temperature limited heater in which current is applied directly to the heater is the ratio of the highest AC or modulated DC resistance below the Curie temperature to the lowest resistance above the Curie temperature for a given current. Turndown ratio for an inductive heater is the ratio of the highest heat output below the Curie temperature to the lowest heat output above the Curie temperature for a given current applied to the heater.

[0407] A "u-shaped wellbore" refers to a wellbore that extends from a first opening in the formation, through at least a portion of the formation, and out through a second opening in the formation. In this context, the wellbore may be only roughly in the shape of a "v" or "u", with the understanding that the "legs" of the "u" do not need to be parallel to each other, or perpendicular to the "bottom" of the "u" for the wellbore to be considered "u-shaped".

[0408] "Upgrade" refers to increasing the quality of hydrocarbons. For example, upgrading heavy hydrocarbons may result in an increase in the API gravity of the heavy hydrocarbons.

[0409] "Visbreaking" refers to the untangling of molecules in fluid during heat treatment and/or to the breaking of large molecules into smaller molecules during heat treatment, which results in a reduction of the viscosity of the fluid.

[0410] "Viscosity" refers to kinematic viscosity at 40 °C unless otherwise specified. Viscosity is as determined by ASTM Method D445.

[0411] "VGO" or "vacuum gas oil" refers to hydrocarbons with a boiling range distribution between 343 °C and 538 °C at 0.101 MPa. VGO content is determined by ASTM Method D5307.

[0412] A "vug" is a cavity, void or large pore in a rock that is commonly lined with mineral precipitates.

[0413] "Wax" refers to a low melting organic mixture, or a compound of high molecular weight that is a solid at lower temperatures and a liquid at higher temperatures, and when in solid form can form a barrier to water. Examples of waxes include animal waxes, vegetable waxes, mineral waxes, petroleum waxes, and synthetic waxes.

[0414] The term "wellbore" refers to a hole in a formation made by drilling or insertion of a conduit into the formation. A wellbore may have a substantially circular cross section, or another cross-sectional shape. As used herein, the terms "well" and "opening," when referring to an opening in the formation may be used interchangeably with the term "wellbore."

[0415] A formation may be treated in various ways to produce many different products. Different stages or processes may be used to treat the formation during an in situ heat treatment process. In some embodiments, one or more sections of the formation are solution mined to remove soluble minerals from the sections. Solution mining minerals may be performed before, during, and/or after the in situ heat treatment process. In some embodiments, the average temperature of one or more sections being solution mined may be maintained below about 120 °C.

[0416] In some embodiments, one or more sections of the formation are heated to remove water from the sections and/or to remove methane and other volatile hydrocarbons from the sections. In some embodiments, the average temperature may be raised from ambient temperature to temperatures below about 220 °C during removal of water and volatile hydrocarbons.

[0417] In some embodiments, one or more sections of the formation are heated to temperatures that allow for movement and/or visbreaking of hydrocarbons in the formation. In some embodiments, the average temperature of one or more sections of the formation are raised to mobilization temperatures of hydrocarbons in the sections (for example, to temperatures ranging from 100 °C to 250 °C, from 120 °C to 240 °C, or from 150 °C to 230 °C).

[0418] In some embodiments, one or more sections are heated to temperatures that allow for pyrolysis reactions in the formation. In some embodiments, the average temperature of one or more sections of the formation may be raised to pyrolysis temperatures of hydrocarbons in the sections (for example, temperatures ranging from 230 °C to 900 °C, from 240 °C to 400 °C or from 250 °C to 350 °C).

[0419] Heating the hydrocarbon containing formation with a plurality of heat sources may establish thermal gradients around the heat sources that raise the temperature of hydrocarbons in the formation to desired temperatures at desired heating rates. The rate of temperature increase through the mobilization temperature range and/or the pyrolysis temperature range for desired products may affect the quality and quantity of the formation fluids produced from the hydrocarbon containing formation. Slowly raising the temperature of the formation through the mobilization temperature range and/or pyrolysis temperature range may allow for the production of high quality, high API gravity hydrocarbons from the formation. Slowly raising the temperature of the formation through the mobilization temperature range and/or pyrolysis temperature range may allow for the removal of a large amount of the hydrocarbons present in the formation as hydrocarbon product.

[0420] In some in situ heat treatment embodiments, a portion of the formation is heated to a desired temperature instead of slowly heating the temperature through a temperature range. In

some embodiments, the desired temperature is 300 °C, 325 °C, or 350 °C. Other temperatures may be selected as the desired temperature.

[0421] Superposition of heat from heat sources allows the desired temperature to be relatively quickly and efficiently established in the formation. Energy input into the formation from the heat sources may be adjusted to maintain the temperature in the formation substantially at a desired temperature.

[0422] Mobilization and/or pyrolysis products may be produced from the formation through production wells. In some embodiments, the average temperature of one or more sections is raised to mobilization temperatures and hydrocarbons are produced from the production wells. The average temperature of one or more of the sections may be raised to pyrolysis temperatures after production due to mobilization decreases below a selected value. In some embodiments, the average temperature of one or more sections may be raised to pyrolysis temperatures without significant production before reaching pyrolysis temperatures. Formation fluids including pyrolysis products may be produced through the production wells.

[0423] In some embodiments, the average temperature of one or more sections may be raised to temperatures sufficient to allow synthesis gas production after mobilization and/or pyrolysis. In some embodiments, hydrocarbons may be raised to temperatures sufficient to allow synthesis gas production without significant production before reaching the temperatures sufficient to allow synthesis gas production. For example, synthesis gas may be produced in a temperature range from about 400 °C to about 1200 °C, about 500 °C to about 1100 °C, or about 550 °C to about 1000 °C. A synthesis gas generating fluid (for example, steam and/or water) may be introduced into the sections to generate synthesis gas. Synthesis gas may be produced from production wells.

[0424] Solution mining, removal of volatile hydrocarbons and water, mobilizing hydrocarbons, pyrolyzing hydrocarbons, generating synthesis gas, and/or other processes may be performed during the in situ heat treatment process. In some embodiments, some processes may be performed after the in situ heat treatment process. Such processes may include, but are not limited to, recovering heat from treated sections, storing fluids (for example, water and/or hydrocarbons) in previously treated sections, and/or sequestering carbon dioxide in previously treated sections.

[0425] FIG. 1 depicts a schematic view of an embodiment of a portion of the in situ heat treatment system for treating the hydrocarbon containing formation. The in situ heat treatment system may include barrier wells 200. Barrier wells are used to form a barrier around a treatment area. The barrier inhibits fluid flow into and/or out of the treatment area. Barrier wells include, but are not limited to, dewatering wells, vacuum wells, capture wells, injection wells, grout wells,

freeze wells, or combinations thereof. In some embodiments, barrier wells 200 are dewatering wells. Dewatering wells may remove liquid water and/or inhibit liquid water from entering a portion of the formation to be heated, or to the formation being heated. In the embodiment depicted in FIG. 1, the barrier wells 200 are shown extending only along one side of heat sources 202, but the barrier wells typically encircle all heat sources 202 used, or to be used, to heat a treatment area of the formation.

[0426] Heat sources 202 are placed in at least a portion of the formation. Heat sources 202 may include heaters such as insulated conductors, conductor-in-conduit heaters, surface burners, flameless distributed combustors, and/or natural distributed combustors. Heat sources 202 may also include other types of heaters. Heat sources 202 provide heat to at least a portion of the formation to heat hydrocarbons in the formation. Energy may be supplied to heat sources 202 through supply lines 204. Supply lines 204 may be structurally different depending on the type of heat source or heat sources used to heat the formation. Supply lines 204 for heat sources may transmit electricity for electric heaters, may transport fuel for combustors, or may transport heat exchange fluid that is circulated in the formation. In some embodiments, electricity for an in situ heat treatment process may be provided by a nuclear power plant or nuclear power plants. The use of nuclear power may allow for reduction or elimination of carbon dioxide emissions from the in situ heat treatment process.

[0427] When the formation is heated, the heat input into the formation may cause expansion of the formation and geomechanical motion. The heat sources may be turned on before, at the same time, or during a dewatering process. Computer simulations may model formation response to heating. The computer simulations may be used to develop a pattern and time sequence for activating heat sources in the formation so that geomechanical motion of the formation does not adversely affect the functionality of heat sources, production wells, and other equipment in the formation.

[0428] Heating the formation may cause an increase in permeability and/or porosity of the formation. Increases in permeability and/or porosity may result from a reduction of mass in the formation due to vaporization and removal of water, removal of hydrocarbons, and/or creation of fractures. Fluid may flow more easily in the heated portion of the formation because of the increased permeability and/or porosity of the formation. Fluid in the heated portion of the formation may move a considerable distance through the formation because of the increased permeability and/or porosity. The considerable distance may be over 1000 m depending on various factors, such as permeability of the formation, properties of the fluid, temperature of the formation, and pressure gradient allowing movement of the fluid. The ability of fluid to travel

considerable distance in the formation allows production wells 206 to be spaced relatively far apart in the formation.

[0429] Production wells 206 are used to remove formation fluid from the formation. In some embodiments, production well 206 includes a heat source. The heat source in the production well may heat one or more portions of the formation at or near the production well. In some in situ heat treatment process embodiments, the amount of heat supplied to the formation from the production well per meter of the production well is less than the amount of heat applied to the formation from a heat source that heats the formation per meter of the heat source. Heat applied to the formation from the production well may increase formation permeability adjacent to the production well by vaporizing and removing liquid phase fluid adjacent to the production well and/or by increasing the permeability of the formation adjacent to the production well by formation of macro and/or micro fractures.

[0430] More than one heat source may be positioned in the production well. A heat source in a lower portion of the production well may be turned off when superposition of heat from adjacent heat sources heats the formation sufficiently to counteract benefits provided by heating the formation with the production well. In some embodiments, the heat source in an upper portion of the production well may remain on after the heat source in the lower portion of the production well is deactivated. The heat source in the upper portion of the well may inhibit condensation and reflux of formation fluid.

[0431] In some embodiments, the heat source in production well 206 allows for vapor phase removal of formation fluids from the formation. Providing heating at or through the production well may: (1) inhibit condensation and/or refluxing of production fluid when such production fluid is moving in the production well proximate the overburden, (2) increase heat input into the formation, (3) increase production rate from the production well as compared to a production well without a heat source, (4) inhibit condensation of high carbon number compounds (C_6 hydrocarbons and above) in the production well, and/or (5) increase formation permeability at or proximate the production well.

[0432] Subsurface pressure in the formation may correspond to the fluid pressure generated in the formation. As temperatures in the heated portion of the formation increase, the pressure in the heated portion may increase as a result of thermal expansion of in situ fluids, increased fluid generation and vaporization of water. Controlling the rate of fluid removal from the formation may allow for control of pressure in the formation. Pressure in the formation may be determined at a number of different locations, such as near or at production wells, near or at heat sources, near or at monitor wells.

[0433] In some hydrocarbon containing formations, production of hydrocarbons from the formation is inhibited until at least some hydrocarbons in the formation have been mobilized and/or pyrolyzed. Formation fluid may be produced from the formation when the formation fluid is of a selected quality. In some embodiments, the selected quality includes an API gravity of at least about 20°, 30°, or 40°. Inhibiting production until at least some hydrocarbons are mobilized and/or pyrolyzed may increase conversion of heavy hydrocarbons to light hydrocarbons. Inhibiting initial production may minimize the production of heavy hydrocarbons from the formation. Production of substantial amounts of heavy hydrocarbons may require expensive equipment and/or reduce the life of production equipment.

[0434] In some hydrocarbon containing formations, hydrocarbons in the formation may be heated to mobilization and/or pyrolysis temperatures before substantial permeability has been generated in the heated portion of the formation. An initial lack of permeability may inhibit the transport of generated fluids to production wells 206. During initial heating, fluid pressure in the formation may increase proximate heat sources 202. The increased fluid pressure may be released, monitored, altered, and/or controlled through one or more heat sources 202. For example, selected heat sources 202 or separate pressure relief wells may include pressure relief valves that allow for removal of some fluid from the formation.

[0435] In some embodiments, pressure generated by expansion of mobilized fluids, pyrolysis fluids or other fluids generated in the formation may be allowed to increase although an open path to production wells 206 or any other pressure sink may not yet exist in the formation. The fluid pressure may be allowed to increase towards a lithostatic pressure. Fractures in the hydrocarbon containing formation may form when the fluid approaches the lithostatic pressure. For example, fractures may form from heat sources 202 to production wells 206 in the heated portion of the formation. The generation of fractures in the heated portion may relieve some of the pressure in the portion. Pressure in the formation may have to be maintained below a selected pressure to inhibit unwanted production, fracturing of the overburden or underburden, and/or coking of hydrocarbons in the formation.

[0436] After mobilization and/or pyrolysis temperatures are reached and production from the formation is allowed, pressure in the formation may be varied to alter and/or control a composition of produced formation fluid, to control a percentage of condensable fluid as compared to non-condensable fluid in the formation fluid, and/or to control an API gravity of formation fluid being produced. For example, decreasing pressure may result in production of a larger condensable fluid component. The condensable fluid component may contain a larger percentage of olefins.

[0437] In some in situ heat treatment process embodiments, pressure in the formation may be maintained high enough to promote production of formation fluid with an API gravity of greater than 20°. Maintaining increased pressure in the formation may inhibit formation subsidence during in situ heat treatment. Maintaining increased pressure may reduce or eliminate the need to compress formation fluids at the surface to transport the fluids in collection conduits to treatment facilities.

[0438] Maintaining increased pressure in a heated portion of the formation may surprisingly allow for production of large quantities of hydrocarbons of increased quality and of relatively low molecular weight. Pressure may be maintained so that formation fluid produced has a minimal amount of compounds above a selected carbon number. The selected carbon number may be at most 25, at most 20, at most 12, or at most 8. Some high carbon number compounds may be entrained in vapor in the formation and may be removed from the formation with the vapor. Maintaining increased pressure in the formation may inhibit entrainment of high carbon number compounds and/or multi-ring hydrocarbon compounds in the vapor. High carbon number compounds and/or multi-ring hydrocarbon compounds may remain in a liquid phase in the formation for significant time periods. The significant time periods may provide sufficient time for the compounds to pyrolyze to form lower carbon number compounds.

[0439] Generation of relatively low molecular weight hydrocarbons is believed to be due, in part, to autogenous generation and reaction of hydrogen in a portion of the hydrocarbon containing formation. For example, maintaining an increased pressure may force hydrogen generated during pyrolysis into the liquid phase within the formation. Heating the portion to a temperature in a pyrolysis temperature range may pyrolyze hydrocarbons in the formation to generate liquid phase pyrolyzation fluids. The generated liquid phase pyrolyzation fluids components may include double bonds and/or radicals. Hydrogen (H_2) in the liquid phase may reduce double bonds of the generated pyrolyzation fluids, thereby reducing a potential for polymerization or formation of long chain compounds from the generated pyrolyzation fluids. In addition, H_2 may also neutralize radicals in the generated pyrolyzation fluids. H_2 in the liquid phase may inhibit the generated pyrolyzation fluids from reacting with each other and/or with other compounds in the formation.

[0440] Formation fluid produced from production wells 206 may be transported through collection piping 208 to treatment facilities 210. Formation fluids may also be produced from heat sources 202. For example, fluid may be produced from heat sources 202 to control pressure in the formation adjacent to the heat sources. Fluid produced from heat sources 202 may be transported through tubing or piping to collection piping 208 or the produced fluid may be transported through tubing or piping directly to treatment facilities 210. Treatment facilities 210

may include separation units, reaction units, upgrading units, fuel cells, turbines, storage vessels, and/or other systems and units for processing produced formation fluids. The treatment facilities may form transportation fuel from at least a portion of the hydrocarbons produced from the formation. In some embodiments, the transportation fuel may be jet fuel, such as JP-8.

[0441] Formation fluid may be hot when produced from the formation through the production wells. Hot formation fluid may be produced during solution mining processes and/or during in situ heat treatment processes. In some embodiments, electricity may be generated using the heat of the fluid produced from the formation. Also, heat recovered from the formation after the in situ process may be used to generate electricity. The generated electricity may be used to supply power to the in situ heat treatment process. For example, the electricity may be used to power heaters, or to power a refrigeration system for forming or maintaining a low temperature barrier. Electricity may be generated using a Kalina cycle, Rankine cycle or other thermodynamic cycle. In some embodiments, the working fluid for the cycle used to generate electricity is aqua ammonia.

[0442] Oil shale formations may have a number of properties that depend on a composition of the hydrocarbons within the formation. Such properties may affect the composition and amount of products that are produced from the oil shale formation during in situ conversion process. Properties of an oil shale formation may be used to determine if and/or how the oil shale formation is to be subjected to in situ heat treatment process.

[0443] Kerogen is composed of organic matter that has been transformed due to a maturation process. The maturation process for kerogen may include two stages: a biochemical stage and a geochemical stage. The biochemical stage typically involves degradation of organic material by aerobic and/or anaerobic organisms. The geochemical stage typically involves conversion of organic matter due to temperature changes and significant pressures. During maturation, oil and gas may be produced as the organic matter of the kerogen is transformed. Kerogen may be classified into four distinct groups: Type I, Type II, Type III, and Type IV. Classification of kerogen type may depend upon precursor materials of the kerogen. The precursor materials transform over time into macerals. Macerals are microscopic structures that have different structures and properties depending on the precursor materials from which they are derived.

[0444] Type I kerogen may be classified as an alginite, since it is developed primarily from algal bodies. Type I kerogen may result from deposits made in lacustrine environments. Type II kerogen may develop from organic matter that was deposited in marine environments. Type III kerogen may generally include vitrinite macerals. Vitrinite is derived from cell walls and/or woody tissues (for example, stems, branches, leaves, and roots of plants). Type III kerogen may be present in most humic coals. Type III kerogen may develop from organic matter that was

deposited in swamps. Type IV kerogen includes the inertinite maceral group. The inertinite maceral group is composed of plant material such as leaves, bark, and stems that have undergone oxidation during the early peat stages of burial diagenesis. Inertinite maceral is chemically similar to vitrinite, but has a high carbon and low hydrogen content.

[0445] Vitrinite reflectance may be used to assess the quality of fluids produced from certain kerogen containing formations. Formations that include kerogen may be assessed/selected for treatment based on a vitrinite reflectance of the kerogen. Vitrinite reflectance is often related to a hydrogen to carbon atomic ratio of a kerogen and an oxygen to carbon atomic ratio of the kerogen. Vitrinite reflectance of a hydrocarbon containing formation may indicate which fluids are producible from a formation upon heating. For example, a vitrinite reflectance of approximately 0.5% to approximately 1.5% may indicate that the kerogen will produce a large quantity of condensable fluids. A vitrinite reflectance of approximately 1.5% to 3.0% may indicate a kerogen having a H/C molar ratio between about 0.25 to about 0.9. Heating of a hydrocarbon formation having a vitrinite reflectance of approximately 1.5% to 3.0% may produce a significant amount (for example, a majority) of methane and hydrogen.

[0446] In some embodiments, hydrocarbon formations containing Type I kerogen have vitrinite reflectance less than 0.5% (for example, between 0.4% and 0.5%). Type I kerogen having a vitrinite reflectance less than 0.5% may contain a significant amount of amorphous organic matter. In some embodiments, kerogen having a vitrinite reflectance less than 0.5% may have relatively high total sulfur content (for example, a total sulfur content between 1.5% and about 2.0% by weight). In certain embodiments, a majority of the total sulfur content in the kerogen is organic sulfur compounds (for example, an organic sulfur content in the kerogen between 1.3% to 1.7% by weight). In some embodiments, hydrocarbon formations having a vitrinite reflectance less than 0.5% may contain a significant amount of calcite and a relatively low amount of dolomite.

[0447] In certain embodiments, Type I kerogen formations may have a mineral content that includes about 85% to 90% by weight calcite (calcium carbonate), about 0.5% to 1.5% by weight dolomite, about 5% to 15% by weight fluorapatite, about 5% to 15% by weight quartz, less than 0.5% by weight clays and/or less than 0.5% by weight iron sulfides (pyrite). Such oil shale formations may have a porosity ranging from about 5% to about 7% and/or a bulk density from about 1.5 to about 2.5 g/cc. Oil shale formations containing primarily calcite may have an organic sulfur content ranging from about 1% to about 2% by weight and an H/C atomic ratio of about 1.4.

[0448] In some embodiments, hydrocarbon formations having a vitrinite reflectance less than 0.5% and/or a relatively high sulfur content may be treated using the in situ heat treatment

process or an in situ conversion process at lower temperatures (for example, about 15 °C lower) relative to treating Type I kerogen having vitrinite reflectance of greater than 0.5% and/or an organic sulfur content of less than 1% by weight and/or Type II-IV kerogens using an in situ conversion process or retorting process. The ability to treat a hydrocarbon formation at lower temperatures may result in energy reductions and increased production of liquid hydrocarbons from the hydrocarbon formation.

[0449] FIG. 2 depicts a schematic representation of a system for treating formation fluid produced from the in situ heat treatment process. Formation fluid 212 may enter fluid separation unit 214 and is separated into in situ heat treatment process liquid stream 216, in situ heat treatment process gas 218 and aqueous stream 220. In some embodiments, liquid stream 216 is transported to other processing units and/or facilities.

[0450] In some embodiments, fluid separation unit 214 includes a quench zone. As produced formation fluid enters the quench zone, quenching fluid such as water, nonpotable water, hydrocarbon diluent, and/or other components may be added to the formation fluid to quench and/or cool the formation fluid to a temperature suitable for handling in downstream processing equipment. Quenching the formation fluid may inhibit formation of compounds that contribute to physical and/or chemical instability of the fluid (for example, inhibit formation of compounds that may precipitate from solution, contribute to corrosion, and/or fouling of downstream equipment and/or piping). The quenching fluid may be introduced into the formation fluid as a spray and/or a liquid stream. In some embodiments, the formation fluid is introduced into the quenching fluid. In some embodiments, the formation fluid is cooled by passing the fluid through a heat exchanger to remove some heat from the formation fluid. The quench fluid may be added to the cooled formation fluid when the temperature of the formation fluid is near or at the dew point of the quench fluid. Quenching the formation fluid near or at the dew point of the quench fluid may enhance solubilization of salts that may cause chemical and/or physical instability of the quenched fluid (for example, ammonium salts). In some embodiments, an amount of water used in the quench is minimal so that salts of inorganic compounds and/or other components do not separate from the mixture. In separation unit 214, at least a portion of the quench fluid may be separated from the quench mixture and recycled to the quench zone with a minimal amount of treatment. Heat produced from the quench may be captured and used in other facilities. In some embodiments, vapor may be produced during the quench. The produced vapor may be sent to gas separation unit 222 and/or sent to other facilities for processing.

[0451] In situ heat treatment process gas 218 may enter gas separation unit 222 to separate gas hydrocarbon stream 224 from the in situ heat treatment process gas. Gas separation unit 222 may include a physical treatment system and/or a chemical treatment system. The physical treatment

system may include, but is not limited to, a membrane unit, a pressure swing adsorption unit, a liquid absorption unit, and/or a cryogenic unit. The chemical treatment system may include units that use amines (for example, diethanolamine or di-isopropanolamine), zinc oxide, sulfolane, water, or mixtures thereof in the treatment process. In some embodiments, gas separation unit 222 uses a Sulfinol gas treatment process for removal of sulfur compounds. Carbon dioxide may be removed using Catacarb® (Catacarb, Overland Park, Kansas, U.S.A.) and/or Benfield (UOP, Des Plaines, Illinois, U.S.A.) gas treatment processes. In some embodiments, the gas separation unit is a rectified adsorption and high pressure fractionation unit. In some embodiments, in situ heat treatment process gas is treated to remove at least 50%, at least 60%, at least 70%, at least 80% or at least 90% by volume of ammonia present in the gas stream.

[0452] In gas separation unit 222, treatment of in situ heat conversion treatment gas 218 removes sulfur compounds, carbon dioxide, and/or hydrogen to produce gas hydrocarbon stream 224. In some embodiments, in situ heat treatment process gas 218 includes about 20 vol% hydrogen, about 30% methane, about 12% carbon dioxide, about 14 vol% C_2 hydrocarbons, about 5 vol% hydrogen sulfide, about 10 vol% C_3 hydrocarbons, about 7 vol% C_4 hydrocarbons, about 2 vol% C_5 hydrocarbons, and mixtures thereof, with the balance being heavier hydrocarbons, water, ammonia, COS, thiols and thiophenes. Gas hydrocarbon stream 224 includes hydrocarbons having a carbon number of at least 3. In some embodiments, in situ treatment process gas 218 is cryogenically treated as described in U.S. Published Patent Application No. 2009-0071652 to Vinegar et al.

[0453] In some embodiments, the process gas stream includes microscopic/molecular species of mercury and/or compounds of mercury. The process gas stream may include dissolved, entrained or solid particulates of metallic mercury, ionic mercury, organometallic compounds of mercury (for example, alkyl mercury), or inorganic compounds of mercury (for example, mercury sulfide). The process gas stream may be processed through a membrane filtration system and/or as described in International Application No. WO 2008/116864 to Den Boestert et al., which is incorporated herein by reference, to remove mercury or mercury compounds from the process gas stream described below. After filtration, the filtered process gas stream (permeate) may have a mercury content of 100 ppbw (parts per billion by weight) or less, 25 ppbw or less, 5 ppbw or less, 2 ppbw or less, or 1 ppbw or less.

[0454] In situ heat treatment process liquid stream 216 enters liquid separation unit 226. In some embodiments, liquid separation unit 226 is not necessary. In liquid separation unit 226, separation of in situ heat treatment process liquid stream 216 produces gas hydrocarbon stream 228 and salty process liquid stream 230. Gas hydrocarbon stream 228 may include hydrocarbons

having a carbon number of at most 5. A portion of gas hydrocarbon stream 228 may be combined with gas hydrocarbon stream 224.

[0455] Salty process liquid stream 230 may be processed through desalting unit 232 to form liquid hydrocarbon stream 234. Desalting unit 232 removes mineral salts and/or water from salty process liquid stream 230 using known desalting and water removal methods. In certain embodiments, desalting unit 232 is positioned ahead of liquid separation unit 226.

[0456] In some embodiments, an additional liquid hydrocarbon stream may be separated from salty process liquid stream 230 in liquid separation unit 226. The additional liquid hydrocarbon stream may be further processed to filtered using a membrane filtration system and/or other filtration known systems to separate asphaltenes and/or to prepare an aromatic enriched diluent stream. Examples of filtration systems to remove asphaltenes and/or make enriched dilute are described in U.S. Patent Application Publication Nos. 2009-0071652 to Vinegar et al.; 2009-0189617 to Burns et al.; and 2010-0071903 to Prince-Wright et al.

[0457] Liquid hydrocarbon stream 234 includes, but is not limited to, hydrocarbons having a carbon number of at least 5 and/or hydrocarbon containing heteroatoms (for example, hydrocarbons containing nitrogen, oxygen, sulfur, and phosphorus). Liquid hydrocarbon stream 234 may include at least 0.001 g, at least 0.005 g, or at least 0.01 g of hydrocarbons with a boiling range distribution between about 95 °C and about 200 °C at 0.101 MPa; at least 0.01 g, at least 0.005 g, or at least 0.001 g of hydrocarbons with a boiling range distribution between about 200 °C and about 300 °C at 0.101 MPa; at least 0.001 g, at least 0.005 g, or at least 0.01 g of hydrocarbons with a boiling range distribution between about 300 °C and about 400 °C at 0.101 MPa; and at least 0.001 g, at least 0.005 g, or at least 0.01 g of hydrocarbons with a boiling range distribution between 400 °C and 650 °C at 0.101 MPa. In some embodiments, liquid hydrocarbon stream 234 contains at most 10% by weight water, at most 5% by weight water, at most 1% by weight water, or at most 0.1% by weight water.

[0458] Liquid hydrocarbon stream 234 includes, but is not limited to, hydrocarbons having a carbon number of at least 5 and/or hydrocarbon containing heteroatoms (for example, hydrocarbons containing nitrogen, oxygen, sulfur, and phosphorus). Liquid hydrocarbon stream 234 may include at least 0.001 g, at least 0.005 g, or at least 0.01 g of hydrocarbons with a boiling range distribution between about 95 °C and about 200 °C at 0.101 MPa; at least 0.01 g, at least 0.005 g, or at least 0.001 g of hydrocarbons with a boiling range distribution between about 200 °C and about 300 °C at 0.101 MPa; at least 0.001 g, at least 0.005 g, or at least 0.01 g of hydrocarbons with a boiling range distribution between about 300 °C and about 400 °C at 0.101 MPa; and at least 0.001 g, at least 0.005 g, or at least 0.01 g of hydrocarbons with a boiling range distribution between 400 °C and 650 °C at 0.101 MPa. In some embodiments, liquid

hydrocarbon stream 234 contains at most 10% by weight water, at most 5% by weight water, at most 1% by weight water, or at most 0.1% by weight water.

[0459] In some embodiments, liquid hydrocarbon stream 234 may include small amounts of dissolved, entrained or solid particulates of metals or metal compounds that may not be removed through conventional filtration methods. Metals and/or metal compounds which may be present in the liquid hydrocarbon stream include iron, copper, mercury, calcium, sodium; silicon or compounds thereof. A total amount of metals and/or metal compounds in the liquid hydrocarbon steam may range from 100 ppbw to about 1000 ppbw.

[0460] As properties of the liquid hydrocarbon stream 234 are changed during processing (for example, TAN, asphaltenes, P-value, olefin content, mobilized fluids content, visbroken fluids content, pyrolyzed fluids content, or combinations thereof), the asphaltenes and other components may become less soluble in the liquid hydrocarbon stream. In some instances, components in the produced fluids and/or components in the separated hydrocarbons may form two phases and/or become insoluble. Formation of two phases, through flocculation of asphaltenes, change in concentration of components in the produced fluids, change in concentration of components in separated hydrocarbons, and/or precipitation of components may cause processing problems (for example, plugging) and/or result in hydrocarbons that do not meet pipeline, transportation, and/or refining specifications. In some embodiments, further treatment of the produced fluids and/or separated hydrocarbons is necessary to produce products with desired properties.

[0461] During processing, the P-value of the separated hydrocarbons may be monitored and the stability of the produced fluids and/or separated hydrocarbons may be assessed. Typically, a P-value that is at most 1.0 indicates that flocculation of asphaltenes from the separated hydrocarbons may occur. If the P-value is initially at least 1.0 and such P-value increases or is relatively stable during heating, then this indicates that the separated hydrocarbons are relatively stable.

[0462] Liquid hydrocarbon stream 234 may be further processed using conventional filtration, hydroprocessing methods and/or methods described in U.S. Patent No. 7,584,789 to Mo et al. and/or U.S. Patent Application Publication No. 2010-0071903 to Prince-Wright et al. to produce commercial products and/or products to be used in an in situ heat treatment process. In some embodiments, the products produced from liquid hydrocarbon stream 234 are suitable for use as transportation fuel. In some embodiments, liquid hydrocarbon stream 234 may be treated to at least partially remove asphaltenes and/or other compounds that may contribute to instability. Removal of the asphaltenes and/or other compounds that may contribute to instability may inhibit plugging in downstream processing units. Removal of the asphaltenes and/or other

compounds that may contribute to instability may enhance processing unit efficiencies and/or prevent plugging of transportation pipelines.

[0463] In some embodiments, liquid hydrocarbon streams produced from a formation may include organonitrogen compounds. Organonitrogen compounds are known to poison precious metal catalyst used for treating hydrocarbon streams to make products suitable for commercial sale and/or transportation (for example, transportation fuels and/or lubricating oils). The formation fluids may include nitrogen levels such that process facilities may deem the fluid unsuitable for processing.

[0464] Removal of organonitrogen compounds from the liquid hydrocarbon stream prior to catalytic treatment of the liquid hydrocarbon streams is desirable. Organonitrogen compounds may be removed through catalytic hydrogenation methods and/or solvent extraction methods. Catalytic hydrogenation methods require high temperatures and catalyst that are not subject to poisoning by nitrogen compounds. The catalytic hydrogenation methods may require high temperatures and/or pressures in addition to requiring high amounts of hydrogen. Hydrogen may not be readily available and/or may need to be manufactured. Since hydrogen has to be supplied for denitrogenation, the use of high amounts of hydrogen may increase the overall cost for removal of nitrogen from the fluids such that process facilities deem the fluids unsuitable.

[0465] Liquid hydrocarbon streams may be extracted with aqueous acid streams to produce a hydrocarbon stream having a minimal amount of organonitrogen compounds and an aqueous stream. The aqueous stream may contain organonitrogen salts. Further processing of the aqueous stream (for example, distillation and/or treatment with base) may result production of a stream rich in organonitrogen compounds. The stream rich in organonitrogen stream may be used as diluent for heavy oil and/or sent to other processing units. U.S. Patent No. 4,287,051 to Curtin describes a method of denitrogenating viscous oils containing a relatively high content of nitrogenous compounds by extracting nitrogenous compounds from a first portion of a viscous oil with an operable acid solvent to produce a raffinate oil having a relatively low concentration of nitrogenous compounds and a extract stream having a high concentration of nitrogenous compounds. The acid solvent is recovered from the extract stream, simultaneously producing a small volume stream of low viscosity oil containing a high concentration of the nitrogenous compounds and referred to as a high nitrogen content oil. The low viscosity high nitrogen content oil is admixed with the remaining first high viscosity bottoms to provide a pumpable mixed stream. Although, aqueous extraction and/or hydrogenation of hydrocarbon streams may produce liquid hydrocarbon streams having a low organonitrogen content, more efficient processes and less costly processes to treat the high nitrogen content oil are desirable. In addition, processes that allow for recycle of waste or low value streams are desirable.

[0466] In some embodiments, liquid stream 234 includes organonitrogen compounds. In some embodiments, liquid stream 234 includes from about 0.1% to greater than 2% by weight nitrogen compounds. In some embodiments, liquid stream 234 includes from about 0.2% to about 1.5% or from 0.5% to about 1% by weight nitrogen compounds. Organonitrogen compounds, for example, alkyl amines, aromatic amines, alkyl amides, aromatic amides, pyridines, pyrazoles, and oxazoles may poison precious metal catalyst used for treating hydrocarbon streams to make products suitable for commercial sale and/or transportation (for example, transportation fuels and/or lubricating oils). Removal of organonitrogen compounds from the liquid hydrocarbon stream prior to catalytic treatment of the liquid hydrocarbon stream may enhance catalyst life of downstream processes. Removal of organonitrogen compounds may allow less severe conditions be used in downstream applications.

[0467] As shown in FIG. 2, a portion of liquid stream 234 is treated with an aqueous acid solution in separation unit 236 to form an aqueous stream 238 and non-aqueous stream 240. In some embodiments, a volume ratio of liquid stream to aqueous acid solution ranges from 0.2 to 0.3 or is about 0.25. Treatment of liquid stream 234 with aqueous acid may be conducted at a temperature ranging from about 90°C to about 150°C at a pressures ranging from about 0.3 MPa to about 0.4 MPa.

[0468] Non-aqueous stream 240 may include non-organonitrogen hydrocarbons. In some embodiments, non-organonitrogen hydrocarbons include compounds that contain only hydrogen and carbon. In some embodiments, non-aqueous stream 240 contains at most 0.01% by weight organonitrogen compounds. In some embodiments, non-aqueous stream 240 contains from about 200 ppmw to about 1000 ppmw, from about 300 ppmw to about 800 ppmw, or from about 500 ppmw to about 700 ppm organonitrogen compounds. Non-aqueous stream 240 may enter one or more hydroprocessing units and/or other processing units positioned after separation unit 236 for further processing to make products suitable for transportation and/or sale. In some embodiments, further processing of non-aqueous stream 240 is not necessary.

[0469] Aqueous acid solution 238 includes water and acids suitable to complex with nitrogen compounds (for example, sulfuric acid, phosphoric acid, acetic acid, formic acid, other suitable acidic compounds or mixtures thereof). Aqueous stream 238 includes salts of the organonitrogen compounds and acid and water. At least a portion of aqueous stream 238 is sent to separation unit 242. In separation unit 242, aqueous stream 238 is separated (for example, distilled) to form aqueous acid stream 244 and concentrated organonitrogen stream 246. Concentrated organonitrogen stream 246 includes organonitrogen compounds, water, and/or acid. Separated aqueous stream 244 may be introduced into separation unit 236. In some embodiments,

separated aqueous stream 244 is combined with another aqueous acid solution prior to entering the separation unit.

[0470] In some embodiments, at least a portion of aqueous stream 238 and/or concentrated organonitrogen stream 246 are introduced in a hydrocarbon portion or layer of subsurface formation that has been at least partially treated by an in situ heat treatment process. Aqueous stream 238 and/or concentrated organonitrogen stream 246 may be heated prior to injection in the formation. In some embodiments, the hydrocarbon portion or layer In some embodiments, at least a portion of aqueous stream 238 and/or concentrated organonitrogen stream 246 are introduced in a hydrocarbon portion or layer of subsurface formation that has been at least partially treated by an in situ heat treatment process. Aqueous stream 238 and/or concentrated organonitrogen stream 246 may be heated prior to injection in the formation. In some embodiments, the hydrocarbon portion or layer includes a shale and/or nahcolite (for example, a nahcolite zone in the Piceance Basin). In some embodiments, the aqueous stream 238 and/or concentrated organonitrogen stream 246 is used a part of the water source for solution mining nahcolite from the formation. In some embodiments, the aqueous stream 238 and/or concentrated organonitrogen stream 246 is introduced in a portion of a formation that contains nahcolite after at least a portion of the nahcolite has been removed. In some embodiments, the aqueous stream 238 and/or concentrated organonitrogen stream 246 is introduced in a portion of a formation that contains nahcolite after at least a portion of the nahcolite has been removed and/or the portion has been at least partially treated using an in situ heat treatment process. The hydrocarbon layer may be heated to temperatures above 200 °C prior to introduction of the aqueous stream. Addition of streams that include organonitrogen compounds may increase the permeability of the hydrocarbon layer (for example, increase the permeability of the oil shale layer), thus flow of formation fluids from the heated hydrocarbon layer to other sections of the formation may be improved. In the heated formation, the organonitrogen compounds may form non-nitrogen containing hydrocarbons, amines, and/or ammonia and at least some of such non-nitrogen containing hydrocarbons, amines and/or ammonia may be produced. In some embodiments, at least some of the acid used in the extraction process is produced. Treatment of the liquid stream as described to produce a stream suitable for further processing and introduction of the organonitrogen stream in a portion of the formation provides an improved, economical process to convert streams deemed unsuitable for processing to be converted to commercial products while overall waste is reduced.

[0471] In some embodiments, streams 234, 246, 240 processed as described in FIG. 2 enter a hydrotreating unit and are contacted with hydrogen in the presence of one or more catalysts to produce hydrotreated liquid streams. Hydrotreating to change one or more desired properties of

the crude feed to meet transportation and/or refinery specifications using known hydrodemetallation, hydrodesulfurization, hydrodenitrofication techniques. Methods to change one or more desired properties of the crude feed are described in U.S. Published Patent Application No. 2009-0071652 to Vinegar et al.

[0472] In some embodiments, hydrotreating non-aqueous stream 240 results in a hydrocarbon stream having a nitrogen compound content of at most 200 ppm by weight, at most 150 ppm, at most 110 ppm, at most 50 ppm, or at most 10 ppm of nitrogen compounds. The hydrotreated liquid stream may have a sulfur compound content of at most 1000 ppm, at most 500 ppm, at most 300 ppm, at most 100 ppm, or at most 10 ppm by weight of sulfur compounds.

[0473] In some embodiments, formation fluid 212 is produced from a hydrocarbon containing formation having a low vitrinite reflectance and/or high sulfur content using an in situ heat treatment process. Such formation fluid may have different characteristics than formation fluid produced from a hydrocarbon containing formation having a vitrinite reflectance of greater than 0.5% and/or a relatively low total sulfur content. The formation fluid produced from formations having a low vitrinite reflectance and/or high sulfur content may include sulfur compounds that can be removed under mild processing conditions. The formation fluid produced from formations having a low vitrinite reflectance and/or high sulfur content may have an API gravity of about 38°, a hydrogen content of about 12% by weight, a total sulfur content of about 3.4% by weight, an oxygen content of about 0.6% by weight, a nitrogen content of about 0.3% by weight and a H/C ratio of about 1.8.

[0474] The liquid process stream may be separated into various distillate hydrocarbon fractions (for example, naphtha, kerosene, and vacuum gas oil fractions). In some embodiments, the naphtha fraction may contain at least 10% by weight thiophenes. The kerosene fraction may contain about 35% by weight thiophenes, about 1% by weight hydrogenated benzothiophenes, and about 4% by weight benzothiophenes. The vacuum gas oil fraction may contain about 10% by weight thiophenes, at least 1.5% by weight hydrogenated benzothiophenes, about 30% benzothiophenes, and about 3% by weight dibenzothiophenes. In some embodiments, the thiophenes may be separated from the produced formation fluid and used as a solvent in the in situ heat treatment process. In some embodiments, hydrocarbon fractions containing thiophenes may be used as solvation fluids in the in situ heat treatment process. In some embodiments, hydrocarbon fractions that include at least 10% by weight thiophenes may be removed from the formation fluid using mild hydrotreating conditions.

[0475] Asphalt/bitumen compositions are a commonly used material for construction purposes, such as road pavement and/or roofing material. Residues from fractional and/or vacuum distillation may be used to prepare asphalt/bitumen compositions. Alternatively, asphalt/bitumen

used in asphalt/bitumen compositions may be obtained from natural resources or by treating a crude oil in a de-asphalting unit to separate the asphalt/bitumen from lighter hydrocarbons in the crude oil. Asphalt/bitumen alone, however, often does not possess all the physical characteristics desirable for many construction purposes. Asphalt/bitumen may be susceptible to moisture loss, permanent deformation (for example, ruts and/or potholes), and/or cracking. Modifiers may be added to asphalt/bitumen to form asphalt/bitumen compositions to improve weatherability of the asphalt/bitumen compositions. Examples, of modifiers include binders, adhesion improvers, antioxidants, extenders, fibers, fillers, oxidants, or combinations thereof. Examples adhesion improvers include fatty acids, inorganic acids, organic amines, amides, phenols, and polyamidoamines. These compositions may have improved characteristics as compared to asphalt/bitumen alone. U.S. Patent No. 4,325,738 to Plancher et al. describes addition of fractions removed from shale oil that contain high amounts of nitrogen may be used as moisture damage inhibiting agents in asphalt/bitumen compositions. The high nitrogen fractions may be obtained by distillation and/or acid extraction. While the composition of the prior art is often effective in improving the weatherability of asphalt-aggregate compositions, asphalt/bitumen compositions having improved resistance to moisture loss, cracking, and deformation are still needed.

[0476] In some embodiments, a residue stream generated from an in situ heat treatment (ISHT) process and/or through further treatment of the liquid stream generated from an ISHT process is blended with asphalt/bitumen to form an ISHT residue/asphalt/bitumen composition. The ISHT residue/asphalt/bitumen blend may have enhanced water sensitivity and/or tensile strength. The ISHT residue/asphalt/bitumen blend may absorb less water and/or have improved tensile strength modulus as compared to other asphalt/bitumen blends made with adhesion improvers. Absorption of less water by ISHT residue/asphalt/bitumen blends may decrease cracking and/or pothole formation in paved roads as compared to asphalt/bitumen blends made with conventional adhesion improvers. Use of ISHT residue in asphalt/bitumen compositions may allow the compositions to be made without or with reduced amounts of expensive adhesion improvers.

[0477] ISHT residue may be generated as from bottoms streams, separators and/or hydrotreating units used to process liquid stream 230. ISHT residue may have at least 50% by weight or at least 80% by weight or at least 90% by weight of hydrocarbons having a boiling point above 538 °C. In some embodiments, ISHT residue has an initial boiling point of at least 400 °C as determined by SIMDIS750, about 50% by weight asphaltenes, about 3% by weight saturates, about 10% by weight aromatics, and about 36% by weight resins as determined by SARA analysis. In some embodiments, ISHT residue may have a total metal content of about 1 ppm to about 500 ppm, from about 10 ppm to about 400 ppm, or from about 100 ppm to about 300 ppm

of metals from Columns 1-14 of the Periodic Table. In some embodiments, ISHT residue may include about 2 ppm aluminum, about 5 ppm calcium, about 100 ppm iron, about 50 ppm nickel, about 10 ppm potassium, about 10 ppm of sodium, and about 5 ppm vanadium as determined by ICP test method such as ASTM Test Method D5185. ISHT residue may be a hard material. For example, ISHT residue may exhibit a penetration of at most 3 at 60 °C (0.1 mm) as measured by ASTM Test Method D243, and a ring-and-ball (R&B) temperature of about 139 °C as determined by ASTM Test Method D36.

[0478] A blend of ISHT residue and asphalt/bitumen may be prepared by reducing the particle size of the ISHT residue (for example, crushing or pulverizing the ISHT residue) and heating the crushed ISHT residue to soften the ISHT particles. The ISHT residue may melt at temperatures above 200 °C. Hot ISHT residue may be added to asphalt/bitumen at a temperature ranging from about 150 °C to about 200 °C, from about 180 °C to about 195 °C, or from about 185 °C to about 195 °C for a period of time to form an ISHT residue/asphalt/bitumen blend.

[0479] The ISHT residue/asphalt/bitumen composition may include from about 0.001% by weight to about 50% by weight, from about 0.05% by weight to about 25% by weight, or from about 0.1% by weight to about 5% by weight of ISHT residue. The ISHT residue/asphalt/bitumen composition may include from about 99.999% by weight to about 50% by weight, from about 99.05% by weight to about 75% by weight, and from about 99.9% by weight to about 95% by weight of asphalt/bitumen. In some embodiments, the blend may include about 20% by weight ISHT residue and about 80% by weight asphalt/bitumen or about 8% by weight ISHT residue and 92% by weight asphalt/bitumen. In some embodiments, additives may be added to the ISHT residue/asphalt/bitumen composition. Additives include, but are not limited to, antioxidants, extenders, fibers, fillers, oxidants, or mixtures thereof.

[0480] The ISHT residue/asphalt/bitumen composition may be used as a binder in paving and/or roofing applications, for example, road paving, shingles, roofing felts, paints, pipecoating, briquettes, thermal and/or phonic insulation, and clay pigeons. In some embodiments, a sufficient amount of ISHT residue may be mixed with asphalt/bitumen to produce an ISHT residue/asphalt/bitumen composition having a 70/100 penetration grade as measured according to EN1426. For example, a mixture of about 8% by weight of ISHT residue and about 91% asphalt/bitumen has a penetration between 70 and 100. The ISHT residue/asphalt/bitumen blend of 70/100 penetration grade is suitable for paving applications.

[0481] Many wells are needed for treating the hydrocarbon formation using the in situ heat treatment process. In some embodiments, vertical or substantially vertical wells are formed in the formation. In some embodiments, horizontal or u-shaped wells are formed in the formation. In some embodiments, combinations of horizontal and vertical wells are formed in the formation.

[0482] A manufacturing approach for forming wellbores in the formation may be used due to the large number of wells that need to be formed for the in situ heat treatment process. The manufacturing approach may be particularly applicable for forming wells for in situ heat treatment processes that utilize u-shaped wells or other types of wells that have long non-vertically oriented sections. Surface openings for the wells may be positioned in lines running along one or two sides of the treatment area. FIG. 3 depicts a schematic representation of an embodiment of a system for forming wellbores of the in situ heat treatment process.

[0483] The manufacturing approach for forming wellbores may include: 1) delivering flat rolled steel to near site tube manufacturing plant that forms coiled tubulars and/or pipe for surface pipelines; 2) manufacturing large diameter coiled tubing that is tailored to the required well length using electrical resistance welding (ERW), wherein the coiled tubing has customized ends for the bottom hole assembly (BHA) and hang off at the wellhead; 3) deliver the coiled tubing to a drilling rig on a large diameter reel; 4) drill to total depth with coil and a retrievable bottom hole assembly; 5) at total depth, disengage the coil and hang the coil on the wellhead; 6) retrieve the BHA; 7) launch an expansion cone to expand the coil against the formation; 8) return empty spool to the tube manufacturing plant to accept a new length of coiled tubing; 9) move the gantry type drilling platform to the next well location; and 10) repeat.

[0484] In situ heat treatment process locations may be distant from established cities and transportation networks. Transporting formed pipe or coiled tubing for wellbores to the in situ process location may be untenable due to the lengths and quantity of tubulars needed for the in situ heat treatment process. One or more tube manufacturing facilities 250 may be formed at or near to the in situ heat treatment process location. The tubular manufacturing facility may form plate steel into coiled tubing. The plate steel may be delivered to tube manufacturing facilities 250 by truck, train, ship or other transportation system. In some embodiments, different sections of the coiled tubing may be formed of different alloys. The tubular manufacturing facility may use ERW to longitudinally weld the coiled tubing.

[0485] Tube manufacturing facilities 250 may be able to produce tubing having various diameters. Tube manufacturing facilities may initially be used to produce coiled tubing for forming wellbores. The tube manufacturing facilities may also be used to produce heater components, piping for transporting formation fluid to surface facilities, and other piping and tubing needs for the in situ heat treatment process.

[0486] Tube manufacturing facilities 250 may produce coiled tubing used to form wellbores in the formation. The coiled tubing may have a large diameter. The diameter of the coiled tubing may be from about 4 inches to about 8 inches in diameter. In some embodiments, the diameter of the coiled tubing is about 6 inches in diameter. The coiled tubing may be placed on large

diameter reels. Large diameter reels may be needed due to the large diameter of the tubing. The diameter of the reel may be from about 10 m to about 50 m. One reel may hold all of the tubing needed for completing a single well to total depth.

[0487] In some embodiments, tube manufacturing facilities 250 has the ability to apply expandable zonal inflow profiler (EZIP) material to one or more sections of the tubing that the facility produces. The EZIP material may be placed on portions of the tubing that are to be positioned near and next to aquifers or high permeability layers in the formation. When activated, the EZIP material forms a seal against the formation that may serve to inhibit migration of formation fluid between different layers. The use of EZIP layers may inhibit saline formation fluid from mixing with non-saline formation fluid.

[0488] The size of the reels used to hold the coiled tubing may prohibit transport of the reel using standard moving equipment and roads. Because tube manufacturing facility 250 is at or near the in situ heat treatment location, the equipment used to move the coiled tubing to the well sites does not have to meet existing road transportation regulations and can be designed to move large reels of tubing. In some embodiments the equipment used to move the reels of tubing is similar to cargo gantries used to move shipping containers at ports and other facilities. In some embodiments, the gantries are wheeled units. In some embodiments, the coiled tubing may be moved using a rail system or other transportation system.

[0489] The coiled tubing may be moved from the tubing manufacturing facility to the well site using gantries 252. Drilling gantry 254 may be used at the well site. Several drilling gantries 254 may be used to form wellbores at different locations. Supply systems for drilling fluid or other needs may be coupled to drilling gantries 254 from central facilities 256.

[0490] Drilling gantry 254 or other equipment may be used to set the conductor for the well. Drilling gantry 254 takes coiled tubing, passes the coiled tubing through a straightener, and a BHA attached to the tubing is used to drill the wellbore to depth. In some embodiments, a composite coil is positioned in the coiled tubing at tube manufacturing facility 250. The composite coil allows the wellbore to be formed without having drilling fluid flowing between the formation and the tubing. The composite coil also allows the BHA to be retrieved from the wellbore. The composite coil may be pulled from the tubing after wellbore formation. The composite coil may be returned to the tubing manufacturing facility to be placed in another length of coiled tubing. In some embodiments, the BHAs are not retrieved from the wellbores.

[0491] In some embodiments, drilling gantry 254 takes the reel of coiled tubing from gantry 252. In some embodiments, gantry 252 is coupled to drilling gantry 254 during the formation of the wellbore. For example, the coiled tubing may be fed from gantry 252 to drilling gantry 254, or

the drilling gantry lifts the gantry to a feed position and the tubing is fed from the gantry to the drilling gantry.

[0492] The wellbore may be formed using the bottom hole assembly, coiled tubing and the drilling gantry. The BHA may be self-seeking to the destination. The BHA may form the opening at a fast rate. In some embodiments, the BHA forms the opening at a rate of about 100 meters per hour.

[0493] After the wellbore is drilled to total depth, the tubing may be suspended from the wellhead. An expansion cone may be used to expand the tubular against the formation. In some embodiments, the drilling gantry is used to install a heater and/or other equipment in the wellbore.

[0494] When drilling gantry 254 is finished at well site 258, the drilling gantry may release gantry 252 with the empty reel or return the empty reel to the gantry. Gantry 252 may take the empty reel back to tube manufacturing facility 250 to be loaded with another coiled tube. Gantries 252 may move on looped path 260 from tube manufacturing facility 250 to well sites 258 and back to the tube manufacturing facility.

[0495] Drilling gantry 254 may be moved to the next well site. Global positioning satellite information, lasers and/or other information may be used to position the drilling gantry at desired locations. Additional wellbores may be formed until all of the wellbores for the in situ heat treatment process are formed.

[0496] In some embodiments, positioning and/or tracking system may be utilized to track gantries 252, drilling gantries 254, coiled tubing reels and other equipment and materials used to develop the in situ heat treatment location. Tracking systems may include bar code tracking systems to ensure equipment and materials arrive where and when needed.

[0497] Some wellbores formed in the formation may be used to facilitate formation of a perimeter barrier around a treatment area. Heat sources in the treatment area may heat hydrocarbons in the formation within the treatment area. The perimeter barrier may be, but is not limited to, a low temperature or frozen barrier formed by freeze wells, a wax barrier formed in the formation, dewatering wells, a grout wall formed in the formation, a sulfur cement barrier, a barrier formed by a gel produced in the formation, a barrier formed by precipitation of salts in the formation, a barrier formed by a polymerization reaction in the formation, and/or sheets driven into the formation. Heat sources, production wells, injection wells, dewatering wells, and/or monitoring wells may be installed in the treatment area defined by the barrier prior to, simultaneously with, or after installation of the barrier.

[0498] A low temperature zone around at least a portion of a treatment area may be formed by freeze wells. In an embodiment, refrigerant is circulated through freeze wells to form low

temperature zones around each freeze well. The freeze wells are placed in the formation so that the low temperature zones overlap and form a low temperature zone around the treatment area. The low temperature zone established by freeze wells is maintained below the freezing temperature of aqueous fluid in the formation. Aqueous fluid entering the low temperature zone freezes and forms the frozen barrier. In other embodiments, the freeze barrier is formed by batch operated freeze wells. A cold fluid, such as liquid nitrogen, is introduced into the freeze wells to form low temperature zones around the freeze wells. The fluid is replenished as needed.

[0499] Grout, wax, polymer or other material may be used in combination with freeze wells to provide a barrier for the in situ heat treatment process. The material may fill cavities (vugs) in the formation and reduces the permeability of the formation. The material may have higher thermal conductivity than gas and/or formation fluid that fills cavities in the formation. Placing material in the cavities may allow for faster low temperature zone formation. The material may form a perpetual barrier in the formation that may strengthen the formation. The use of material to form the barrier in unconsolidated or substantially unconsolidated formation material may allow for larger well spacing than is possible without the use of the material. The combination of the material and the low temperature zone formed by freeze wells may constitute a double barrier for environmental regulation purposes. In some embodiments, the material is introduced into the formation as a liquid, and the liquid sets in the formation to form a solid. The material may be, but is not limited to, fine cement, micro fine cement, sulfur, sulfur cement, viscous thermoplastics, and/or waxes. The material may include surfactants, stabilizers or other chemicals that modify the properties of the material. For example, the presence of surfactant in the material may promote entry of the material into small openings in the formation.

[0500] Material may be introduced into the formation through freeze well wellbores. The material may be allowed to set. The integrity of the wall formed by the material may be checked. The integrity of the material wall may be checked by logging techniques and/or by hydrostatic testing. If the permeability of a section formed by the material is too high, additional material may be introduced into the formation through freeze well wellbores. After the permeability of the section is sufficiently reduced, freeze wells may be installed in the freeze well wellbores.

[0501] Material may be injected into the formation at a pressure that is high, but below the fracture pressure of the formation. In some embodiments, injection of material is performed in 16 m increments in the freeze wellbore. Larger or smaller increments may be used if desired. In some embodiments, material is only applied to certain portions of the formation. For example, material may be applied to the formation through the freeze wellbore only adjacent to aquifer zones and/or to relatively high permeability zones (for example, zones with a permeability greater than about 0.1 darcy). Applying material to aquifers may inhibit migration of water from

one aquifer to a different aquifer. For material placed in the formation through freeze well wellbores, the material may inhibit water migration between aquifers during formation of the low temperature zone. The material may also inhibit water migration between aquifers when an established low temperature zone is allowed to thaw.

[0502] In some embodiments, the material used to form a barrier may be fine cement and micro fine cement. Cement may provide structural support in the formation. Fine cement may be ASTM type 3 Portland cement. Fine cement may be less expensive than micro fine cement. In an embodiment, a freeze wellbore is formed in the formation. Selected portions of the freeze wellbore are grouted using fine cement. Then, micro fine cement is injected into the formation through the freeze wellbore. The fine cement may reduce the permeability down to about 10 millidarcy. The micro fine cement may further reduce the permeability to about 0.1 millidarcy. After the grout is introduced into the formation, a freeze wellbore canister may be inserted into the formation. The process may be repeated for each freeze well that will be used to form the barrier.

[0503] In some embodiments, fine cement is introduced into every other freeze wellbore. Micro fine cement is introduced into the remaining wellbores. For example, grout may be used in a formation with freeze wellbores set at about 5 m spacing. A first wellbore is drilled and fine cement is introduced into the formation through the wellbore. A freeze well canister is positioned in the first wellbore. A second wellbore is drilled 10 m away from the first wellbore. Fine cement is introduced into the formation through the second wellbore. A freeze well canister is positioned in the second wellbore. A third wellbore is drilled between the first wellbore and the second wellbore. In some embodiments, grout from the first and/or second wellbores may be detected in the cuttings of the third wellbore. Microfine cement is introduced into the formation through the third wellbore. A freeze wellbore canister is positioned in the third wellbore. The same procedure is used to form the remaining freeze wells that will form the barrier around the treatment area.

[0504] Fiber optic temperature monitoring systems may also be used to monitor temperatures in heated portions of the formation during in situ heat treatment processes. Temperature monitoring systems positioned in production wells, heater wells, injection wells, and/or monitor wells may be used to measure temperature profiles in treatment areas subjected to in situ heat treatment processes. The fiber of a fiber optic cable used in the heated portion of the formation may be clad with a reflective material to facilitate retention of a signal or signals transmitted down the fiber. In some embodiments, the fiber is clad with gold, copper, nickel, aluminum and/or alloys thereof. The cladding may be formed of a material that is able to withstand chemical and temperature conditions in the heated portion of the formation. For example, gold cladding may

allow an optical sensor to be used up to temperatures of 700 °C. In some embodiments, the fiber is clad with aluminum. The fiber may be dipped in or run through a bath of liquid aluminum. The clad fiber may then be allowed to cool to secure the aluminum to the fiber. The gold or aluminum cladding may reduce hydrogen darkening of the optical fiber.

[0505] In some embodiments, two or more rows of freeze wells are located about all or a portion of the perimeter of the treatment area to form a thick interconnected low temperature zone. Thick low temperature zones may be formed adjacent to areas in the formation where there is a high flow rate of aqueous fluid in the formation. The thick barrier may ensure that breakthrough of the frozen barrier established by the freeze wells does not occur.

[0506] In some embodiments, a double barrier system is used to isolate a treatment area. The double barrier system may be formed with a first barrier and a second barrier. The first barrier may be formed around at least a portion of the treatment area to inhibit fluid from entering or exiting the treatment area. The second barrier may be formed around at least a portion of the first barrier to isolate an inter-barrier zone between the first barrier and the second barrier. The inter-barrier zone may have a thickness from about 1 m to about 300 m. In some embodiments, the thickness of the inter-barrier zone is from about 10 m to about 100 m, or from about 20 m to about 50 m.

[0507] The double barrier system may allow greater project depths than a single barrier system. Greater depths are possible with the double barrier system because the stepped differential pressures across the first barrier and the second barrier is less than the differential pressure across a single barrier. The smaller differential pressures across the first barrier and the second barrier make a breach of the double barrier system less likely to occur at depth for the double barrier system as compared to the single barrier system. In some embodiments, additional barriers may be positioned to connect the inner barrier to the outer barrier. The additional barriers may further strengthen the double barrier system and define compartments that limit the amount of fluid that can pass from the inter-barrier zone to the treatment area should a breach occur in the first barrier.

[0508] The first barrier and the second barrier may be the same type of barrier or different types of barriers. In some embodiments, the first barrier and the second barrier are formed by freeze wells. In some embodiments, the first barrier is formed by freeze wells, and the second barrier is a grout wall. The grout wall may be formed of cement, sulfur, sulfur cement, or combinations thereof. In some embodiments, a portion of the first barrier and/or a portion of the second barrier is a natural barrier, such as an impermeable rock formation.

[0509] In some embodiments, one or both barriers may be formed from wellbores positioned in the formation. The position of the wellbores used to form the second barrier may be adjusted

relative to the wellbores used to form the first barrier to limit a separation distance between a breach or portion of the barrier that is difficult to form and the nearest wellbore. For example, if freeze wells are used to form both barriers of a double barrier system, the position of the freeze wells may be adjusted to facilitate formation of the barriers and limit the distance between a potential breach and the closest wells to the breach. Adjusting the position of the wells of the second barrier relative to the wells of the first barrier may also be used when one or more of the barriers are barriers other than freeze barriers (for example, dewatering wells, cement barriers, grout barriers, and/or wax barriers).

[0510] In some embodiments, wellbores for forming the first barrier are formed in a row in the formation. During formation of the wellbores, logging techniques and/or analysis of cores may be used to determine the principal fracture direction and/or the direction of water flow in one or more layers of the formation. In some embodiments, two or more layers of the formation may have different principal fracture directions and/or the directions of water flow that need to be addressed. In such formations, three or more barriers may need to be formed in the formation to allow for formation of the barriers that inhibit inflow of formation fluid into the treatment area or outflow of formation fluid from the treatment area. Barriers may be formed to isolate particular layers in the formation.

[0511] The principal fracture direction and/or the direction of water flow may be used to determine the placement of wells used to form the second barrier relative to the wells used to form the first barrier. The placement of the wells may facilitate formation of the first barrier and the second barrier.

[0512] FIG. 4 depicts a schematic representation of barrier wells 200 used to form a first barrier and barrier wells 200' used to form a second barrier when the principal fracture direction and/or the direction of water flow is at angle *A* relative to the first barrier. The principal fracture direction and/or direction of water flow is indicated by arrow 356. The case where angle *A* is 0 is the case where the principal fracture direction and/or the direction of water flow is substantially normal to the barriers. Spacing between two adjacent barrier wells 200 of the first barrier or between barrier wells 200' of the second barrier are indicated by distance *s*. The spacing *s* may be 2 m, 3 m, 10 m or greater. Distance *d* indicates the separation distance between the first barrier and the second barrier. Distance *d* may be less than *s,* equal to *s, or* greater than *s*. Barrier wells 200' of the second barrier may have offset distance *od* relative to barrier wells 200 of the first barrier. Offset distance *od* may be calculated by the equation:

(EQN. 1) $od = s/2 - d*\tan(A)$.

[0513] Using the *od* according to EQN. 1 maintains a maximum separation distance of *s*/4 between a barrier well and a regular fracture extending between the barriers. Having a maximum

separation distance of *s*/4 by adjusting the offset distance based on the principal fracture direction and/or the direction of water flow may enhance formation of the first barrier and/or second barrier. Having a maximum separation distance of *s*/4 by adjusting the offset distance of wells of the second barrier relative to the wells of the first barrier based on the principal fracture direction and/or the direction of water flow may reduce the time needed to reform the first barrier and/or the second barrier should a breach of the first barrier and/or the second barrier occur.

[0514] In some embodiments, *od* may be set at a value between the value generated by EQN. 1 and the worst case value. The worst case value of *od* may be if barrier wells 200 of the first freeze barrier and barrier wells 200' of the second barrier are located along the principal fracture direction and/or direction of water flow (along arrow 356). In such a case, the maximum separation distance would be *s*/2. Having a maximum separation distance of *s*/2 may slow the time needed to form the first barrier and/or the second barrier, or may inhibit formation of the barriers.

[0515] In some embodiments, the barrier wells for the treatment area are freeze wells. Vertically positioned freeze wells and/or horizontally positioned freeze wells may be positioned around sides of the treatment area. If the upper layer (the overburden) or the lower layer (the underburden) of the formation is likely to allow fluid flow into the treatment area or out of the treatment area, horizontally positioned freeze wells may be used to form an upper and/or a lower barrier for the treatment area. In some embodiments, an upper barrier and/or a lower barrier may not be necessary if the upper layer and/or the lower layer are at least substantially impermeable. If the upper freeze barrier is formed, portions of heat sources, production wells, injection wells, and/or dewatering wells that pass through the low temperature zone created by the freeze wells forming the upper freeze barrier wells may be insulated and/or heat traced so that the low temperature zone does not adversely affect the functioning of the heat sources, production wells, injection wells and/or dewatering wells passing through the low temperature zone.

[0516] To form a low temperature barrier, spaced apart wellbores may be formed in the formation where the barrier is to be formed. Piping may be placed in the wellbores. A low temperature heat transfer fluid may be circulated through the piping to reduce the temperature adjacent to the wellbores. The low temperature zone around the wellbores may expand outward. Eventually the low temperature zones produced by two adjacent wellbores merge. The temperature of the low temperature zones may be sufficiently low to freeze formation fluid so that a substantially impermeable barrier is formed. The wellbore spacing may be from about 1 m to 3 m or more.

[0517] Wellbore spacing may be a function of a number of factors, including formation composition and properties, formation fluid and properties, time available for forming the barrier,

and temperature and properties of the low temperature heat transfer fluid. In general, a very cold temperature of the low temperature heat transfer fluid allows for a larger spacing and/or for quicker formation of the barrier. A very cold temperature may be -20° C or less.

[0518] In some embodiments, a double barrier system is used to isolate a treatment area. The double barrier system may be formed with a first barrier and a second barrier. The first barrier may be formed around at least a portion of the treatment area to inhibit fluid from entering or exiting the treatment area. The second barrier may be formed around at least a portion of the first barrier to isolate an inter-barrier zone between the first barrier and the second barrier. The double barrier system may allow greater formation depths than a single barrier system. Greater depths are possible with the double barrier system because the stepped differential pressures across the first barrier and the second barrier is less than the differential pressure across a single barrier. The smaller differential pressures across the first barrier and the second barrier make a breach of the double barrier system less likely to occur at depth for the double barrier system as compared to the single barrier system.

[0519] The double barrier system reduces the probability that a barrier breach will affect the treatment area or the formation on the outside of the double barrier. That is, the probability that the location and/or time of occurrence of the breach in the first barrier will coincide with the location and/or time of occurrence of the breach in the second barrier is low, especially if the distance between the first barrier and the second barrier is relatively large (for example, greater than about 15 m). Having a double barrier may reduce or eliminate influx of fluid into the treatment area following a breach of the first barrier or the second barrier. The treatment area may not be affected if the second barrier breaches. If the first barrier breaches, only a portion of the fluid in the inter-barrier zone is able to enter the contained zone. Also, fluid from the contained zone will not pass the second barrier. Recovery from a breach of a barrier of the double barrier system may require less time and fewer resources than recovery from a breach of a single barrier system. For example, reheating a treatment area zone following a breach of a double barrier system may require less energy than reheating a similarly sized treatment area zone following a breach of a single barrier system.

[0520] The first barrier and the second barrier may be the same type of barrier or different types of barriers. In some embodiments, the first barrier and the second barrier are formed by freeze wells. In some embodiments, the first barrier is formed by freeze wells, and the second barrier is a grout wall. The grout wall may be formed of cement, sulfur, sulfur cement, or combinations thereof (for example, fine cement and micro fine cement). In some embodiments, a portion of the first barrier and/or a portion of the second barrier is a natural barrier, such as an impermeable rock formation.

[0521] Grout, wax, polymer or other material may be used in combination with freeze wells to provide a barrier for the in situ heat treatment process. The material may fill cavities in the formation and reduces the permeability of the formation. The material may have higher thermal conductivity than gas and/or formation fluid that fills cavities in the formation. Placing material in the cavities may allow for faster low temperature zone formation. The material may form a perpetual barrier in the formation that may strengthen the formation. The use of material to form the barrier in unconsolidated or substantially unconsolidated formation material may allow for larger well spacing than is possible without the use of the material. The combination of the material and the low temperature zone formed by freeze wells may constitute a double barrier for environmental regulation purposes. In some embodiments, the material is introduced into the formation as a liquid, and the liquid sets in the formation to form a solid. The material may be, but is not limited to, fine cement, micro fine cement, sulfur, sulfur cement, viscous thermoplastics, and/or waxes. The material may include surfactants, stabilizers or other chemicals that modify the properties of the material. For example, the presence of surfactant in the material may promote entry of the material into small openings in the formation.

[0522] Material may be introduced into the formation through freeze well wellbores. The material may be allowed to set. The integrity of the wall formed by the material may be checked. The integrity of the material wall may be checked by logging techniques and/or by hydrostatic testing. If the permeability of a section formed by the material is too high, additional material may be introduced into the formation through freeze well wellbores. After the permeability of the section is sufficiently reduced, freeze wells may be installed in the freeze well wellbores.

[0523] Material may be injected into the formation at a pressure that is high, but below the fracture pressure of the formation. In some embodiments, injection of material is performed in 16 m increments in the freeze wellbore. Larger or smaller increments may be used if desired. In some embodiments, material is only applied to certain portions of the formation. For example, material may be applied to the formation through the freeze wellbore only adjacent to aquifer zones and/or to relatively high permeability zones (for example, zones with a permeability greater than about 0.1 darcy). Applying material to aquifers may inhibit migration of water from one aquifer to a different aquifer. For material placed in the formation through freeze well wellbores, the material may inhibit water migration between aquifers during formation of the low temperature zone. The material may also inhibit water migration between aquifers when an established low temperature zone is allowed to thaw.

[0524] In certain embodiments, portions of a formation where a barrier is to be installed may be intentionally fractured. The portions which are to be fractured may be subjected to a pressure which is above the formation fracturing pressure but below the overburden fracture pressure. For

example, steam may be injected through one or more injection/production wells above the formation fracturing pressure may increase the permeability. In some embodiments, one or more gas pressure pulses may be used to fracture portions of the formation. Fractured portion surrounding the wellbores may allow materials used to create barriers to permeate through the formation more readily.

[0525] In some embodiments, if the upper layer (the overburden) or the lower layer (the underburden) of the formation is likely to allow fluid flow into the treatment area or out of the treatment area, horizontally positioned freeze wells may be used to form an upper and/or a lower barrier for the treatment area. In some embodiments, an upper barrier and/or a lower barrier may not be necessary if the upper layer and/or the lower layer are at least substantially impermeable. If the upper freeze barrier is formed, portions of heat sources, production wells, injection wells, and/or dewatering wells that pass through the low temperature zone created by the freeze wells forming the upper freeze barrier wells may be insulated and/or heat traced so that the low temperature zone does not adversely affect the functioning of the heat sources, production wells, injection wells and/or dewatering wells passing through the low temperature zone.

[0526] In some embodiments, one or both barriers may be formed from wellbores positioned in the formation. The position of the wellbores used to form the second barrier may be adjusted relative to the wellbores used to form the first barrier to limit a separation distance between a breach, or portion of the barrier that is difficult to form, and the nearest wellbore. For example, if freeze wells are used to form both barriers of a double barrier system, the position of the freeze wells may be adjusted to facilitate formation of the barriers and limit the distance between a potential breach and the closest wells to the breach. Adjusting the position of the wells of the second barrier relative to the wells of the first barrier may also be used when one or more of the barriers are barriers other than freeze barriers (for example, dewatering wells, cement barriers, grout barriers, and/or wax barriers).

[0527] In some embodiments, wellbores for forming the first barrier are formed in a row in the formation. During formation of the wellbores, logging techniques and/or analysis of cores may be used to determine the principal fracture direction and/or the direction of water flow in one or more layers of the formation. In some embodiments, two or more layers of the formation may have different principal fracture directions and/or the directions of water flow that need to be addressed. In such formations, three or more barriers may need to be formed in the formation to allow for formation of the barriers that inhibit inflow of formation fluid into the treatment area or outflow of formation fluid from the treatment area. Barriers may be formed to isolate particular layers in the formation.

[0528] The principal fracture direction and/or the direction of water flow may be used to determine the placement of wells used to form the second barrier relative to the wells used to form the first barrier. The placement of the wells may facilitate formation of the first barrier and the second barrier.

[0529] As discussed there are several benefits to employing a double barrier system to isolate a treatment area. Freeze wells may be used to form the first barrier and/or the second barrier. Problems may arise when freeze wells are used to form one or more barriers of a double barrier system. For example, a first barrier formed from freeze wells may expand further than is desirable. The first barrier may expand to a point such that the first barrier merges with a second barrier for a single barrier. Upon formation of a single barrier advantages associated with a double barrier may be lost. It would be beneficial to inhibit one or more portions of the first barrier and second barrier from forming a single combined barrier.

[0530] In some embodiments, a double barrier system may include a system which functions, during use, to inhibit one or more portions of the first barrier and second barrier from forming a single combined barrier. In some embodiments, the system may include an injection system. The injection system may inject one or more materials in the space which exists between the first barrier and the second barrier. The material may inhibit one or more portions of the first barrier and second barrier from forming a single combined barrier. Typically, the material may include one or more fluids which inhibit freezing of water and/or any other fluids in the space between the first barrier and the second barrier. The fluids may be heated to further inhibit expansion of one or more of the barriers. The fluids may be heated as a result of processes related to the in situ heat treatment of hydrocarbons in the treatment area defined by the barriers and/or in situ heat treatment processes occurring in other portions of the hydrocarbon containing formation.

[0531] In some embodiments, the system may circulate fluids through the space which exists between the first barrier and the second barrier. For example, fluids may be injected through an at least first wellbore in a first portion of the space and removed through an at least second wellbore in a second portion of the space. The wellbores may serve multiple purposes (for example, heating, production, etc.). The fluids circulating through the space may be cooled by the barriers. Cooled fluids which are removed from the space between the barriers may be used for processes related to the in situ heat treatment of hydrocarbons in the treatment area defined by the barriers and/or in situ heat treatment processes occurring in other portions of the hydrocarbon containing formation. In some embodiments, the fluids may be recirculated through the space between the barriers, therefore, the system may include a subsystem on the surface for reheating fluids before they are reinjected through the first wellbore.

[0532] In some embodiments, fluids may include water. Injecting water in the space between the first barrier and second barrier may inhibit the two barriers from combining with one another. Water injected in the space may be available from processes related to the in situ heat treatment of hydrocarbons in the treatment area defined by the barriers and/or in situ heat treatment processes occurring in other portions of the hydrocarbon containing formation. Water is a commonly available fluid in certain parts of the world and using local sources of water for injection reduces costs (for example, costs associated with transportation). Water from local sources adjacent the treatment area may be employed for injection in the space.

[0533] In some embodiments, local sources of water are natural source of water or at least result from natural sources. When water from local sources is used fluctuation in availability of such sources must be taken into consideration. Natural sources of water may be subject to seasonal changes of availability. For example, when treatment areas are adjacent to mountainous regions runoff water from melting snows may be employed. Local water source including, but not limited to, seasonal water sources may be used for in situ heat treatment processes (for example, inhibiting one or more portions of the first barrier and second barrier from forming a single combined barrier, forming barriers by injecting the water in freeze wells). In some embodiments, injected fluids may include additives. Additives may include other fluids, solid materials which may or may not dissolve in the injected fluids. Additive may serve a variety of different purposes. For example, additives may function to decrease the freezing point of the fluid used below its naturally occurring freeze point without any additives. An example of a fluid with additives capable of reducing the fluids freezing point may include water with salt dissolved in the water. Water is an inexpensive and commonly available fluid whose properties are well known; however, typically, frozen barriers are formed from predominantly water, making waters use as a circulating fluid to inhibit merging of multiple barriers potentially problematic. The frozen barriers are by definition cold enough to potentially freeze any water circulated through the space between the barriers, potentially contributing to the problem of merging barriers. Salt is a relatively inexpensive and commonly available material which is soluble in water and reduces the freezing point of water.

[0534] In some embodiments, heat may be provided to the space between barriers. Providing heat to the space between two barriers may inhibit the barriers from merging with one another. A plurality of heater wells may be positioned in the space between the barriers. The number of heater wells required may be dependent on several factors (for example, the dimensions of the space between the barriers, the materials forming the space between the barriers, the type of heaters used or combinations thereof). Heat provided by the heater wells positioned between

barrier wells may inhibit the barriers from merging without endangering the structural integrity of the barriers.

[0535] In some embodiments, combinations of different strategies to inhibit the merging of barriers may be employed. For example, fluids may be circulated through the space between barriers while at the same time using heater wells to heat the space.

[0536] FIG. 5 depicts an embodiment of double barrier system 1302. The perimeter of treatment area 730 may be surrounded by first barrier 958. First barrier 958 may be surrounded by second barrier 1304. Inter-barrier zones 1306 may be isolated between first barrier 958, second barrier 1304 and partitions 1308. Creating sections with partitions 1308 between first barrier 958 and second barrier 1304 limits the amount of fluid held in individual inter-barrier zones 1306. Partitions 1308 may strengthen double barrier system 1302. In some embodiments, the double barrier system may not include partitions.

[0537] The inter-barrier zone may have a thickness from about 1 m to about 300 m. In some embodiments, the thickness of the inter-barrier zone is from about 10 m to about 100 m, or from about 20 m to about 50 m.

[0538] Pumping/monitor wells 960 may be positioned in contained zone 730, inter-barrier zones 1306, and/or outer zone 1310 outside of second barrier 1304. Pumping/monitor wells 960 allow for removal of fluid from treatment area 730, inter-barrier zones 1306, or outer zone 1310. Pumping/monitor wells 960 also allow for monitoring of fluid levels in treatment area 730, inter-barrier zones 1306, and outer zone 1310. Pumping/monitor wells 960 positioned in inter-barrier zones 1306 may be used to inject and/or circulate fluids to inhibit merging of first barrier 958 and second barrier 1304.

[0539] In some embodiments, a portion of treatment area 730 is heated by heat sources. The closest heat sources to first barrier 958 may be installed a desired distance away from the first barrier. In some embodiments, the desired distance between the closest heat sources and first barrier 958 is in a range between about 5 m and about 300 m, between about 10 m and about 200 m, or between about 15 m and about 50 m. For example, the desired distance between the closest heat sources and first barrier 958 may be about 40 m.

[0540] FIG. 5 depicts only one embodiment of how a barrier using freeze wells may be laid out. The barrier surrounding the treatment area may be arranged in any number of shapes and configurations. Different configurations may result in the barrier having different properties and advantages (and/or disadvantages). Different formations may benefit from different barrier configurations. Forming a barrier in a formation where water within the formation does not flow much may require less planning relative to another formation where large volumes of water move underground rapidly. Large volumes of relatively rapidly moving water through a formation may

create excessive amounts of pressure against a formed barrier and consequently increases the difficulty in initially forming the barrier. Changing a shape of a perimeter of the barrier may reduce the pressures exerted by such exterior (relative to the interior treatment area) formation water flows, and thus increasing the structural stability of the barrier.

[0541] In some embodiments, a barrier may be oriented at an angle relative to a direction of a flow of water in a formation. Forming the barrier at an angle may reduce the pressure of the water exerted on the exterior of the barrier. Large volumes of relatively rapidly moving water through a formation may create excessive amounts of pressure therefore increasing the difficulty in initially forming the barrier. Several strategies may be employed to form the barrier under the increased pressures exerted by flowing water.

[0542] A barrier may be formed using freeze wells arranged oriented at an angle relative to a direction of a flow of water in a formation. In some embodiments, freeze wells may be activated sequentially. Activating freeze wells sequentially may allow flowing water to more easily flow around portions of a barrier formed by freeze wells activated first. Allowing water to initially flow through portions of a barrier as the barrier forms may alleviate pressure exerted by the flowing water upon the forming barrier, thereby increasing chances of successfully creating a structurally stable barrier. FIG. 6 depicts a schematic representation of dual barrier containment system 1302. Treatment area 730 may be surrounded by double barrier containment system 1302 formed by sequential activation of freeze wells 1300. Freeze wells 1300A may be activated first to form a first portion of second barrier 1304. Upon formation of the first portion of second barrier 1304, freeze wells 1300B may be activated. Freeze wells 1300B, when activated, form a second portion of second barrier 1304. Upon formation of the second portion of second barrier 1304, freeze wells 1300C may be activated. Freeze wells 1300C, when activated, form a third portion of second barrier 1304. Sequential activation of freeze wells 1300 may continue until second barrier 1304 is formed. In some embodiments, after formation of second barrier 1304, first barrier 958 may be formed. Formation of first barrier 958 may not require sequential activation to form due to the protection provided by second barrier 1304.

[0543] In some embodiments, controlling the pressure within the treatment area of the hydrocarbon containing formation may assist in successfully creating a structurally stable barrier. Pressure in the treatment area may be increased or decreased relative to outside of the treatment area in order to affect the flow of fluids between the interior and exterior of the treatment area. There are of course a number of ways of increasing/decreasing the pressure inside the treatment area known to one skilled in the art (for example, using injection/productions wells in the treatment area). There are many advantages to controlling the pressure in the treatment area as regards to forming and/or repairing barriers surrounding at least a portion of the treatment area.

When a barrier formed by freeze wells is near completion the interior pressure of the treatment area may be changed to equilibrate the interior pressure and the exterior pressure of the treatment area. Equilibrating the pressure may substantially reduce or eliminate the flow of fluids between the exterior and the interior of the treatment area through any openings in the barrier. Equilibrating the pressure may reduce the pressure on the barrier itself. Reducing or eliminating the flow of fluids between the exterior and the interior of the treatment area through any openings in the barrier may facilitate the final formation of the barrier hindered by the flow of fluid through openings in the barrier.

[0544] In some embodiments, one or more horizontal freeze wells may be employed to temporarily divert water flowing through a formation. Diverting water flow at least temporarily while a barrier is being formed may expedite formation of the barrier. Horizontal freeze well may be used to form an underground channel or culvert to divert water at least temporarily while one or more vertical barriers around a treatment area are formed.

[0545] In addition to needing to resist pressure and forces exerted by subsurface water flows, barriers need to resist pressures and forces exerted by geomechanical motion. When the formation is heated, the heat input into the formation may cause expansion of the formation and geomechanical motion. Geomechanical motion may include geomechanical shifting, shearing, and/or expansion stress in the formation. Changing a shape of a perimeter of the barrier may reduce the pressures exerted by such forces as geomechanical motion. Extra forces may be exerted on one or more of the edges of a barrier. In some embodiments, a barrier may have a perimeter which forms a corrugated surface on the barrier. A corrugated barrier may be more resistant to geomechanical motion. In some embodiments, a barrier may extend down vertically in a formation and continue underneath a formation. Extending a barrier (for example, a barrier formed by freeze wells) down and underneath a formation may be more resistant to geomechanical motion.

[0546] The pressure difference between the water flow in the formation and one or more portions of a barrier (for example, a frozen barrier formed by freeze wells) may be referred to as disjoining pressure. Disjoining pressure may inhibit the formation of a barrier. The formation may be analyzed to assess the most appropriate places to position barriers. To overcome the problems caused by disjoining pressure on the formation of barriers, barriers may be formed rapidly. In some embodiments, super cooled fluids (for example, liquid nitrogen) may be used to rapidly freeze water to form the barrier.

[0547] FIG. 7 depicts a cross-sectional view of double barrier system 1302 used to isolate treatment area 730 in the formation. The formation may include one or more fluid bearing zones 1312 and one or more impermeable zones 1314. First barrier 958 may at least partially surround

treatment area 730. Second barrier 1304 may at least partially surround first barrier 958. In some embodiments, impermeable zones 1314 are located above and/or below treatment area 730. Thus, treatment area 730 is sealed around the sides and from the top and bottom. In some embodiments, one or more paths 1316 are formed to allow communication between two or more fluid bearing zones 1312 in treatment area 730. Fluid in treatment area 730 may be pumped from the zone. Fluid in inter-barrier zone 1306 and fluid in outer zone 1310 is inhibited from reaching the treatment area. During in situ conversion of hydrocarbons in treatment area 730, formation fluid generated in the treatment area is inhibited from passing into inter-barrier zone 1306 and outer zone 1310.

[0548] After sealing treatment area 730, fluid levels in a given fluid bearing zone 1312 may be changed so that the fluid head in inter-barrier zone 1306 and the fluid head in outer zone 1310 are different. The amount of fluid and/or the pressure of the fluid in individual fluid bearing zones 1312 may be adjusted after first barrier 958 and second barrier 1304 are formed. The ability to maintain different amounts of fluid and/or pressure in fluid bearing zones 1312 may indicate the formation and completeness of first barrier 958 and second barrier 1304. Having different fluid head levels in treatment area 730, fluid bearing zones 1312 in inter-barrier zone 1306, and in the fluid bearing zones in outer zone 1310 allows for determination of the occurrence of a breach in first barrier 958 and/or second barrier 1304. In some embodiments, the differential pressure across first barrier 958 and second barrier 1304 is adjusted to reduce stresses applied to first barrier 958 and/or second barrier 1304, or stresses on certain strata of the formation.

[0549] Subsurface formations include dielectric media. Dielectric media may exhibit conductivity, relative dielectric constant, and loss tangents at temperatures below 100 °C. Loss of conductivity, relative dielectric constant, and dissipation factor may occur as the formation is heated to temperatures above 100 °C due to the loss of moisture contained in the interstitial spaces in the rock matrix of the formation. To prevent loss of moisture, formations may be heated at temperatures and pressures that minimize vaporization of water. Conductive solutions may be added to the formation to help maintain the electrical properties of the formation.

[0550] In some embodiments, the relative dielectric constant and/or the electrical resistance may be measured on the inside and outside of freeze wells. Monitoring the dielectric constant and/or the electrical resistance may be used to monitor one or more freeze wells. A decrease in the voltage difference between the interior and the exterior of the well may indicate a leak has formed in the barrier.

[0551] Some fluid bearing zones 1312 may contain native fluid that is difficult to freeze because of a high salt content or compounds that reduce the freezing point of the fluid. If first barrier 958 and/or second barrier 1304 are low temperature zones established by freeze wells, the native fluid

that is difficult to freeze may be removed from fluid bearing zones 1312 in inter-barrier zone 1306 through pumping/monitor wells 960. The native fluid is replaced with a fluid that the freeze wells are able to more easily freeze.

[0552] In some embodiments, pumping/monitor wells 960 may be positioned in treatment area 730, inter-barrier zone 1306, and/or outer zone 1310. Pumping/monitor wells 960 may be used to test for freeze completion of frozen barriers and/or for pressure testing frozen barriers and/or strata. Pumping/monitor wells 960 may be used to remove fluid and/or to monitor fluid levels in treatment area 730, inter-barrier zone 1306, and/or outer zone 1310. Using pumping/monitor wells 960 to monitor fluid levels in contained zone 730, inter-barrier zone 1306, and/or outer zone 1310 may allow detection of a breach in first barrier 958 and/or second barrier 1304. Pumping/monitor wells 960 allow pressure in treatment area 730, each fluid bearing zone 1312 in inter-barrier zone 1306, and each fluid bearing zone in outer zone 1310 to be independently monitored so that the occurrence and/or the location of a breach in first barrier 958 and/or second barrier 1304 can be determined.

[0553] In some embodiments, fluid pressure in inter-barrier zone 1306 is maintained greater than the fluid pressure in treatment area 730, and less than the fluid pressure in outer zone 1310. If a breach of first barrier 958 occurs, fluid from inter-barrier zone 1306 flows into treatment area 730, resulting in a detectable fluid level drop in the inter-barrier zone. If a breach of second barrier 1304 occurs, fluid from the outer zone flows into inter-barrier zone 1306, resulting in a detectable fluid level rise in the inter-barrier zone.

[0554] A breach of first barrier 958 may allow fluid from inter-barrier zone 1306 to enter treatment area 730. FIG. 8 depicts breach 1318 in first barrier 958 of double barrier containment system 1302. Arrow 1320 indicates flow direction of fluid 1322 from inter-barrier zone 1306 to treatment area 730 through breach 1318. The fluid level in fluid bearing zone 1312 proximate breach 1318 of inter-barrier zone 1306 falls to the height of the breach.

[0555] Path 1316 allows fluid 1322 to flow from breach 1318 to the bottom of treatment area 730, increasing the fluid level in the bottom of the contained zone. The volume of fluid that flows into treatment area 730 from inter-barrier zone 1306 is typically small compared to the volume of the treatment area. The volume of fluid able to flow into treatment area 730 from inter-barrier zone 1306 is limited because second barrier 1304 inhibits recharge of fluid 1322 into the affected fluid bearing zone. In some embodiments, the fluid that enters treatment area 730 may be pumped from the treatment area using pumping/monitor wells 960 in the treatment area. In some embodiments, the fluid that enters treatment area 730 may be evaporated by heaters in the treatment area that are part of the in situ conversion process system. The recovery time for the heated portion of treatment area 730 from cooling caused by the introduction of fluid from

inter-barrier zone 1306 is brief. The recovery time may be less than a month, less than a week, or less than a day.

[0556] Pumping/monitor wells 960 in inter-barrier zone 1306 may allow assessment of the location of breach 1318. When breach 1318 initially forms, fluid flowing into treatment area 730 from fluid bearing zone 1312 proximate the breach creates a cone of depression in the fluid level of the affected fluid bearing zone in inter-barrier zone 1306. Time analysis of fluid level data from pumping/monitor wells 960 in the same fluid bearing zone as breach 1318 can be used to determine the general location of the breach.

[0557] When breach 1318 of first barrier 958 is detected, pumping/monitor wells 960 located in the fluid bearing zone that allows fluid to flow into treatment area 730 may be activated to pump fluid out of the inter-barrier zone. Pumping the fluid out of the inter-barrier zone reduces the amount of fluid 1322 that can pass through breach 1318 into treatment area 730.

[0558] Breach 1318 may be caused by ground shift. If first barrier 958 is a low temperature zone formed by freeze wells, the temperature of the formation at breach 1318 in the first barrier is below the freezing point of fluid 1322 in inter-barrier zone 1306. Passage of fluid 1322 from inter-barrier zone 1306 through breach 1318 may result in freezing of the fluid in the breach and self-repair of first barrier 958.

[0559] A breach of the second barrier may allow fluid in the outer zone to enter the inter-barrier zone. The first barrier may inhibit fluid entering the inter-barrier zone from reaching the treatment area. FIG. 9 depicts breach 1318 in second barrier 1304 of double barrier system 1302. Arrow 1320 indicates flow direction of fluid 1322 from outside of second barrier 1304 to inter-barrier zone 1306 through breach 1318. As fluid 1322 flows through breach 1318 in second barrier 1304, the fluid level in the portion of inter-barrier zone 1306 proximate the breach rises from initial level 1324 to a level that is equal to level 1326 of fluid in the same fluid bearing zone in outer zone 1310. An increase of fluid 1322 in fluid bearing zone 1312 may be detected by pumping/monitor well 960 positioned in the fluid bearing zone proximate breach 1318 (for example, a rise of fluid from initial level 1324 to level 1326 in pumping monitor well 960 in inter-barrier zone 1306).

[0560] Breach 1318 may be caused by ground shift. If second barrier 1304 is a low temperature zone formed by freeze wells, the temperature of the formation at breach 1318 in the second barrier is below the freezing point of fluid 1322 entering from outer zone 1310. Fluid from outer zone 1310 in breach 1318 may freeze and self-repair second barrier 1304.

[0561] First barrier and second barrier of the double barrier containment system may be formed by freeze wells. In certain embodiments, the first barrier is formed before the second barrier. The cooling load needed to maintain the first barrier may be significantly less than the cooling

load needed to form the first barrier. After formation of the first barrier, the excess cooling capacity that the refrigeration system used to form the first barrier may be used to form a portion of the second barrier. In some embodiments, the second barrier is formed first and the excess cooling capacity that the refrigeration system used to form the second barrier is used to form a portion of the first barrier. After the first and second barriers are formed, excess cooling capacity supplied by the refrigeration system or refrigeration systems used to form the first barrier and the second barrier may be used to form a barrier or barriers around the next contained zone that is to be processed by the in situ conversion process.

[0562] In situ heat treatment processes and solution mining processes may heat the treatment area, remove mass from the treatment area, and greatly increase the permeability of the treatment area. In certain embodiments, the treatment area after being treated may have a permeability of at least 0.1 darcy. In some embodiments, the treatment area after being treated has a permeability of at least 1 darcy, of at least 10 darcy, or of at least 100 darcy. The increased permeability allows the fluid to spread in the formation into fractures, microfractures, and/or pore spaces in the formation. Outside of the treatment area, the permeability may remain at the initial permeability of the formation. The increased permeability allows fluid introduced to flow easily within the formation.

[0563] In certain embodiments, a barrier may be formed in the formation after a solution mining process and/or an in situ heat treatment process by introducing a fluid into the formation. The barrier may inhibit formation fluid from entering the treatment area after the solution mining and/or in situ heat treatment processes have ended. The barrier formed by introducing fluid into the formation may allow for isolation of the treatment area.

[0564] The fluid introduced into the formation to form a barrier may include wax, bitumen, heavy oil, sulfur, polymer, gel, saturated saline solution, and/or one or more reactants that react to form a precipitate, solid or high viscosity fluid in the formation. In some embodiments, bitumen, heavy oil, reactants and/or sulfur used to form the barrier are obtained from treatment facilities associated with the in situ heat treatment process. For example, sulfur may be obtained from a Claus process used to treat produced gases to remove hydrogen sulfide and other sulfur compounds.

[0565] The fluid may be introduced into the formation as a liquid, vapor, or mixed phase fluid. The fluid may be introduced into a portion of the formation that is at an elevated temperature. In some embodiments, the fluid is introduced into the formation through wells located near a perimeter of the treatment area. The fluid may be directed away from the treatment area. The elevated temperature of the formation maintains or allows the fluid to have a low viscosity so that the fluid moves away from the wells. A portion of the fluid may spread outwards in the

formation towards a cooler portion of the formation. The relatively high permeability of the formation allows fluid introduced from one wellbore to spread and mix with fluid introduced from other wellbores. In the cooler portion of the formation, the viscosity of the fluid increases, a portion of the fluid precipitates, and/or the fluid solidifies or thickens so that the fluid forms the barrier to flow of formation fluid into or out of the treatment area.

[0566] In some embodiments, a low temperature barrier formed by freeze wells surrounds all or a portion of the treatment area. As the fluid introduced into the formation approaches the low temperature barrier, the temperature of the formation becomes colder. The colder temperature increases the viscosity of the fluid, enhances precipitation, and/or solidifies the fluid to form the barrier to the flow of formation fluid into or out of the formation. The fluid may remain in the formation as a highly viscous fluid or a solid after the low temperature barrier has dissipated.

[0567] In certain embodiments, saturated saline solution is introduced into the formation. Components in the saturated saline solution may precipitate out of solution when the solution reaches a colder temperature. The solidified particles may form the barrier to the flow of formation fluid into or out of the formation. The solidified components may be substantially insoluble in formation fluid.

[0568] In certain embodiments, a bitumen barrier may be formed in the formation in situ. An outer portion of a treatment area may be heated into a selected temperature range to mobilize bitumen (for example, between about 80 °C and about 110 °C). Over the selected temperature range, a sufficient viscosity of the bitumen is maintained to allow the bitumen to move away from the heater wellbores. In certain embodiments, heaters in the heater wellbores are temperature limited heaters with temperatures near the mobilization temperature of bitumen such that the temperature near the heaters stays relatively constant and above temperatures resulting in the formation of solid bitumen. In some embodiments, the region adjacent to the wellbores used to mobilize bitumen may be heated to a temperature above the mobilization temperature, but below the pyrolysis temperature of hydrocarbons in the formation for a period of time. In certain embodiments, the formation is heated to temperatures above the mobilization temperature, but below the pyrolysis temperature of hydrocarbon in the formation for about six months. After the period of time, the heaters may be turned off and the temperature in the wellbores may be monitored (for example, using a fiber optic temperature monitoring system).

[0569] In some embodiments, a temperature of bitumen in a portion of the formation between two adjacent heaters is influenced by both heaters. In some embodiments, the portion of the formation that is heated is between an existing barrier (for example, a barrier formed using a freeze well) and the heaters on the outer portion of the formation.

[0570] In some embodiments, the heater wellbores used to heat bitumen are dedicated heater wellbores. One or more heater wellbores may be located at an edge of an area to be treated using the in situ heat treatment process. Heater wellbores may be located a selected distance from the edge of the treatment area. For example, a distance of heater wellbore from the edge of the treatment area may range from about 20 m to about 40 m or from about 25 m to about 35 m. Heater wellbores may be about 1 m to about 2 m above or below a layer containing water. In some embodiments, a dedicated heater wellbore is used to mobilize bitumen to form a barrier.

[0571] As the mobilized bitumen enters portions of the formation below the mobilization temperature, the bitumen may solidify and form a barrier to fluid flow in the formation. In some embodiments, the mobilized bitumen is allowed to flow and diffuse into the formation from the wellbores.

[0572] In some embodiments, the bitumen enters portions of the formation containing water cooler than the average temperature of the mobilized bitumen. The water may be in a portion of the formation below or substantially below the heated portion containing bitumen. In some embodiments, the water is in a portion of the formation that is between at least two heaters. The water may be cooled, partially frozen, and/or frozen using one or more freeze wells. In some embodiments, pressure in the section containing water is adjusted or maintained (for example, at about 1 MPa) to move water in the section towards the mobilized bitumen. In some embodiments, the bitumen gravity drains to a portion of the formation containing the cool water.

[0573] In some embodiments, the portion of the formation containing water is assessed to determine the amount of water saturation in the water bearing portion. Based on the assessed water saturation in the water bearing portion, a selected number of wells and spacing of the selected wells may be determined to ensure that sufficient bitumen is mobilized to form a barrier of a desired thickness. For example, sufficient wells and spacing may be determined to create a barrier having a thickness of 10 m.

[0574] Contact of bitumen with the cool water solidifies the bitumen and/or a bitumen/water mixture and forms a barrier to fluid flow in the formation. Contact of the bitumen with the cool water may expand the bitumen and/or bitumen/water mixture to form the barrier. Heating may be stopped, and the formation may be allowed to naturally cool such that the bitumen and/or bitumen/water mixture in the formation solidifies. Location of the bitumen barrier may be determined using pressure tests. The integrity of the formed barrier may be tested using pulse tests and/or tracer tests.

[0575] After the bitumen barrier is formed, the area inside the bitumen barrier may be treated using an in situ process. The treatment area may be heated using heaters in the treatment area. Temperature in the treatment area is controlled such that the bitumen barrier is not compromised.

In some embodiments, after the bitumen barrier is formed, heaters near the bitumen barrier may be exchanged with freeze canisters and used as freeze wells to form additional freeze barriers. Mobilized and/or visbroken hydrocarbons may be produced from production wells in the treatment area during the in situ heat treatment process.

[0576] FIGS. 10 and 11 depict representations of embodiments of forming a bitumen barrier in a subsurface formation. Heaters 412A in treatment area 1328 and/or treatment area 1334 in hydrocarbon layer 388 may provide a selected amount of heat to the formation sufficient to mobilize bitumen near heaters 412A. As shown in FIG. 11, heater 412A is located a selected distance 1336 from treatment area 1328. Mobilized bitumen may move away from heaters 412A and/or drain towards section 1330 in the formation. As shown in FIG. 10, section 1330 is between section 1328 and section 1334. It should be understood, however, that section 1330 may be adjacent to or surround section 1328 and/or section 1334. At least a portion of section 1330 contains water. As shown in FIG. 11, section 1330 may be a fractured layer below section 1328. Water in section 1330 may be cooled using freeze wells 1300 (shown in FIG. 10). Adjusting and/or maintaining a pressure in freeze wells 1300 may move water in section 1330 towards section 1328 and/or section 1334.

[0577] As the bitumen enters section 1330 and contacts water in the section, the bitumen/water mixture may solidify along the perimeter of section 1330 or in the section to form bitumen barrier 1338. Formation of bitumen barrier 1338 may inhibit fluid from flowing in or out of section 1328 and/or section 1334. For example, water may be inhibited from flowing out of section 1330 into section 1328 and/or section 1334. After formation of the bitumen barrier, heat from heaters 412B may heat section 1328 and/or section 1334 to mobilize hydrocarbons in the sections towards production wells 206. Mobilized hydrocarbons may be produced from production wells 206. In some embodiments, mobilized hydrocarbons from section 1328 and/or sections 1334 are produced from other portions of the formation. In some embodiments, at least some of heaters 412A may be converted to freeze wells to form additional barriers in hydrocarbon layer 388.

[0578] A potential source of heat loss from the heated formation is due to reflux in wells. Refluxing occurs when vapors condense in a well and flow into a portion of the well adjacent to the heated portion of the formation. Vapors may condense in the well adjacent to the overburden of the formation to form condensed fluid. Condensed fluid flowing into the well adjacent to the heated formation absorbs heat from the formation. Heat absorbed by condensed fluids cools the formation and necessitates additional energy input into the formation to maintain the formation at a desired temperature. Some fluids that condense in the overburden and flow into the portion of the well adjacent to the heated formation may react to produce undesired compounds and/or

coke. Inhibiting fluids from refluxing may significantly improve the thermal efficiency of the in situ heat treatment system and/or the quality of the product produced from the in situ heat treatment system.

[0579] For some well embodiments, the portion of the well adjacent to the overburden section of the formation is cemented to the formation. In some well embodiments, the well includes packing material placed near the transition from the heated section of the formation to the overburden. The packing material inhibits formation fluid from passing from the heated section of the formation into the section of the wellbore adjacent to the overburden. Cables, conduits, devices, and/or instruments may pass through the packing material, but the packing material inhibits formation fluid from passing up the wellbore adjacent to the overburden section of the formation.

[0580] In some embodiments, one or more baffle systems may be placed in the wellbores to inhibit reflux. The baffle systems may be obstructions to fluid flow into the heated portion of the formation. In some embodiments, refluxing fluid may revaporize on the baffle system before coming into contact with the heated portion of the formation.

[0581] In some embodiments, a gas may be introduced into the formation through wellbores to inhibit reflux in the wellbores. In some embodiments, gas may be introduced into wellbores that include baffle systems to inhibit reflux of fluid in the wellbores. The gas may be carbon dioxide, methane, nitrogen or other desired gas. In some embodiments, the introduction of gas may be used in conjunction with one or more baffle systems in the wellbores. The introduced gas may enhance heat exchange at the baffle systems to help maintain top portions of the baffle systems colder than the lower portions of the baffle systems.

[0582] The flow of production fluid up the well to the surface is desired for some types of wells, especially for production wells. Flow of production fluid up the well is also desirable for some heater wells that are used to control pressure in the formation. The overburden, or a conduit in the well used to transport formation fluid from the heated portion of the formation to the surface, may be heated to inhibit condensation on or in the conduit. Providing heat in the overburden, however, may be costly and/or may lead to increased cracking or coking of formation fluid as the formation fluid is being produced from the formation.

[0583] To avoid the need to heat the overburden or to heat the conduit passing through the overburden, one or more diverters may be placed in the wellbore to inhibit fluid from refluxing into the wellbore adjacent to the heated portion of the formation. In some embodiments, the diverter retains fluid above the heated portion of the formation. Fluids retained in the diverter may be removed from the diverter using a pump, gas lifting, and/or other fluid removal technique. In certain embodiments, two or more diverters that retain fluid above the heated

portion of the formation may be located in the production well. Two or more diverters provide a simple way of separating initial fractions of condensed fluid produced from the in situ heat treatment system. A pump may be placed in each of the diverters to remove condensed fluid from the diverters.

[0584] In some embodiments, the diverter directs fluid to a sump below the heated portion of the formation. An inlet for a lift system may be located in the sump. In some embodiments, the intake of the lift system is located in casing in the sump. In some embodiments, the intake of the lift system is located in an open wellbore. The sump is below the heated portion of the formation. The intake of the pump may be located 1 m, 5 m, 10 m, 20 m or more below the deepest heater used to heat the heated portion of the formation. The sump may be at a cooler temperature than the heated portion of the formation. The sump may be more than 10 °C, more than 50 °C, more than 75 °C, or more than 100 °C below the temperature of the heated portion of the formation. A portion of the fluid entering the sump may be liquid. A portion of the fluid entering the sump may condense within the sump. The lift system moves the fluid in the sump to the surface.

[0585] Production well lift systems may be used to efficiently transport formation fluid from the bottom of the production wells to the surface. Production well lift systems may provide and maintain the maximum required well drawdown (minimum reservoir producing pressure) and producing rates. The production well lift systems may operate efficiently over a wide range of high temperature/multiphase fluids (gas/vapor/steam/water/hydrocarbon liquids) and production rates expected during the life of a typical project. Production well lift systems may include dual concentric rod pump lift systems, chamber lift systems and other types of lift systems.

[0586] Temperature limited heaters may be in configurations and/or may include materials that provide automatic temperature limiting properties for the heater at certain temperatures. In certain embodiments, ferromagnetic materials are used in temperature limited heaters. Ferromagnetic material may self-limit temperature at or near the Curie temperature of the material and/or the phase transformation temperature range to provide a reduced amount of heat when a time-varying current is applied to the material. In certain embodiments, the ferromagnetic material self-limits temperature of the temperature limited heater at a selected temperature that is approximately the Curie temperature and/or in the phase transformation temperature range. In certain embodiments, the selected temperature is within about 35 °C, within about 25 °C, within about 20 °C, or within about 10 °C of the Curie temperature and/or the phase transformation temperature range. In certain embodiments, ferromagnetic materials are coupled with other materials (for example, highly conductive materials, high strength materials, corrosion resistant materials, or combinations thereof) to provide various electrical and/or

mechanical properties. Some parts of the temperature limited heater may have a lower resistance (caused by different geometries and/or by using different ferromagnetic and/or non-ferromagnetic materials) than other parts of the temperature limited heater. Having parts of the temperature limited heater with various materials and/or dimensions allows for tailoring the desired heat output from each part of the heater.

[0587] Temperature limited heaters may be more reliable than other heaters. Temperature limited heaters may be less apt to break down or fail due to hot spots in the formation. In some embodiments, temperature limited heaters allow for substantially uniform heating of the formation. In some embodiments, temperature limited heaters are able to heat the formation more efficiently by operating at a higher average heat output along the entire length of the heater. The temperature limited heater operates at the higher average heat output along the entire length of the heater because power to the heater does not have to be reduced to the entire heater, as is the case with typical constant wattage heaters, if a temperature along any point of the heater exceeds, or is about to exceed, a maximum operating temperature of the heater. Heat output from portions of a temperature limited heater approaching a Curie temperature and/or the phase transformation temperature range of the heater automatically reduces without controlled adjustment of the time-varying current applied to the heater. The heat output automatically reduces due to changes in electrical properties (for example, electrical resistance) of portions of the temperature limited heater. Thus, more power is supplied by the temperature limited heater during a greater portion of a heating process.

[0588] In certain embodiments, the system including temperature limited heaters initially provides a first heat output and then provides a reduced (second heat output) heat output, near, at, or above the Curie temperature and/or the phase transformation temperature range of an electrically resistive portion of the heater when the temperature limited heater is energized by a time-varying current. The first heat output is the heat output at temperatures below which the temperature limited heater begins to self-limit. In some embodiments, the first heat output is the heat output at a temperature about 50 °C, about 75 °C, about 100 °C, or about 125 °C below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic material in the temperature limited heater.

[0589] The temperature limited heater may be energized by time-varying current (alternating current or modulated direct current) supplied at the wellhead. The wellhead may include a power source and other components (for example, modulation components, transformers, and/or capacitors) used in supplying power to the temperature limited heater. The temperature limited heater may be one of many heaters used to heat a portion of the formation.

[0590] In certain embodiments, the temperature limited heater includes a conductor that operates as a skin effect or proximity effect heater when time-varying current is applied to the conductor. The skin effect limits the depth of current penetration into the interior of the conductor. For ferromagnetic materials, the skin effect is dominated by the magnetic permeability of the conductor. The relative magnetic permeability of ferromagnetic materials is typically between 10 and 1000 (for example, the relative magnetic permeability of ferromagnetic materials is typically at least 10 and may be at least 50, 100, 500, 1000 or greater). As the temperature of the ferromagnetic material is raised above the Curie temperature, or the phase transformation temperature range, and/or as the applied electrical current is increased, the magnetic permeability of the ferromagnetic material decreases substantially and the skin depth expands rapidly (for example, the skin depth expands as the inverse square root of the magnetic permeability). The reduction in magnetic permeability results in a decrease in the AC or modulated DC resistance of the conductor near, at, or above the Curie temperature, the phase transformation temperature range, and/or as the applied electrical current is increased. When the temperature limited heater is powered by a substantially constant current source, portions of the heater that approach, reach, or are above the Curie temperature and/or the phase transformation temperature range may have reduced heat dissipation. Sections of the temperature limited heater that are not at or near the Curie temperature and/or the phase transformation temperature range may be dominated by skin effect heating that allows the heater to have high heat dissipation due to a higher resistive load.

[0591] Curie temperature heaters have been used in soldering equipment, heaters for medical applications, and heating elements for ovens (for example, pizza ovens). Some of these uses are disclosed in U.S. Patent Nos. 5,579,575 to Lamome et al.; 5,065,501 to Henschen et al.; and 5,512,732 to Yagnik et al. U.S. Patent No. 4,849,611 to Whitney et al. describe a plurality of discrete, spaced-apart heating units including a reactive component, a resistive heating component, and a temperature responsive component.

[0592] An advantage of using the temperature limited heater to heat hydrocarbons in the formation is that the conductor is chosen to have a Curie temperature and/or a phase transformation temperature range in a desired range of temperature operation. Operation within the desired operating temperature range allows substantial heat injection into the formation while maintaining the temperature of the temperature limited heater, and other equipment, below design limit temperatures. Design limit temperatures are temperatures at which properties such as corrosion, creep, and/or deformation are adversely affected. The temperature limiting properties of the temperature limited heater inhibit overheating or burnout of the heater adjacent to low thermal conductivity "hot spots" in the formation. In some embodiments, the temperature limited heater is able to lower or control heat output and/or withstand heat at temperatures above

25 °C, 37 °C, 100 °C, 250 °C, 500 °C, 700 °C, 800 °C, 900 °C, or higher up to 1131 °C, depending on the materials used in the heater.

[0593] The temperature limited heater allows for more heat injection into the formation than constant wattage heaters because the energy input into the temperature limited heater does not have to be limited to accommodate low thermal conductivity regions adjacent to the heater. For example, in Green River oil shale there is a difference of at least a factor of 3 in the thermal conductivity of the lowest richness oil shale layers and the highest richness oil shale layers. When heating such a formation, substantially more heat is transferred to the formation with the temperature limited heater than with the conventional heater that is limited by the temperature at low thermal conductivity layers. The heat output along the entire length of the conventional heater needs to accommodate the low thermal conductivity layers so that the heater does not overheat at the low thermal conductivity layers and burn out. The heat output adjacent to the low thermal conductivity layers that are at high temperature will reduce for the temperature limited heater, but the remaining portions of the temperature limited heater that are not at high temperature will still provide high heat output. Because heaters for heating hydrocarbon formations typically have long lengths (for example, at least 10 m, 100 m, 300 m, 500 m, 1 km or more up to about 10 km), the majority of the length of the temperature limited heater may be operating below the Curie temperature and/or the phase transformation temperature range while only a few portions are at or near the Curie temperature and/or the phase transformation temperature range of the temperature limited heater.

[0594] The use of temperature limited heaters allows for efficient transfer of heat to the formation. Efficient transfer of heat allows for reduction in time needed to heat the formation to a desired temperature. For example, in Green River oil shale, pyrolysis typically requires 9.5 years to 10 years of heating when using a 12 m heater well spacing with conventional constant wattage heaters. For the same heater spacing, temperature limited heaters may allow a larger average heat output while maintaining heater equipment temperatures below equipment design limit temperatures. Pyrolysis in the formation may occur at an earlier time with the larger average heat output provided by temperature limited heaters than the lower average heat output provided by constant wattage heaters. For example, in Green River oil shale, pyrolysis may occur in 5 years using temperature limited heaters with a 12 m heater well spacing. Temperature limited heaters counteract hot spots due to inaccurate well spacing or drilling where heater wells come too close together. In certain embodiments, temperature limited heaters allow for increased power output over time for heater wells that have been spaced too far apart, or limit power output for heater wells that are spaced too close together. Temperature limited heaters also supply more

power in regions adjacent the overburden and underburden to compensate for temperature losses in these regions.

[0595] Temperature limited heaters may be advantageously used in many types of formations. For example, in tar sands formations or relatively permeable formations containing heavy hydrocarbons, temperature limited heaters may be used to provide a controllable low temperature output for reducing the viscosity of fluids, mobilizing fluids, and/or enhancing the radial flow of fluids at or near the wellbore or in the formation. Temperature limited heaters may be used to inhibit excess coke formation due to overheating of the near wellbore region of the formation.

[0596] In some embodiments, the use of temperature limited heaters eliminates or reduces the need for expensive temperature control circuitry. For example, the use of temperature limited heaters eliminates or reduces the need to perform temperature logging and/or the need to use fixed thermocouples on the heaters to monitor potential overheating at hot spots.

[0597] In certain embodiments, phase transformation (for example, crystalline phase transformation or a change in the crystal structure) of materials used in a temperature limited heater change the selected temperature at which the heater self-limits. Ferromagnetic material used in the temperature limited heater may have a phase transformation (for example, a transformation from ferrite to austenite) that decreases the magnetic permeability of the ferromagnetic material. This reduction in magnetic permeability is similar to reduction in magnetic permeability due to the magnetic transition of the ferromagnetic material at the Curie temperature. The Curie temperature is the magnetic transition temperature of the ferrite phase of the ferromagnetic material. The reduction in magnetic permeability results in a decrease in the AC or modulated DC resistance of the temperature limited heater near, at, or above the temperature of the phase transformation and/or the Curie temperature of the ferromagnetic material.

[0598] The phase transformation of the ferromagnetic material may occur over a temperature range. The temperature range of the phase transformation depends on the ferromagnetic material and may vary, for example, over a range of about 5 °C to a range of about 200 °C. Because the phase transformation takes place over a temperature range, the reduction in the magnetic permeability due to the phase transformation takes place over the temperature range. The reduction in magnetic permeability may also occur hysteretically over the temperature range of the phase transformation. In some embodiments, the phase transformation back to the lower temperature phase of the ferromagnetic material is slower than the phase transformation to the higher temperature phase (for example, the transition from austenite back to ferrite is slower than the transition from ferrite to austenite). The slower phase transformation back to the lower temperature phase may cause hysteretic operation of the heater at or near the phase

transformation temperature range that allows the heater to slowly increase to higher resistance after the resistance of the heater reduces due to high temperature.

[0599] In some embodiments, the phase transformation temperature range overlaps with the reduction in the magnetic permeability when the temperature approaches the Curie temperature of the ferromagnetic material. The overlap may produce a faster drop in electrical resistance versus temperature than if the reduction in magnetic permeability is solely due to the temperature approaching the Curie temperature. The overlap may also produce hysteretic behavior of the temperature limited heater near the Curie temperature and/or in the phase transformation temperature range.

[0600] In certain embodiments, the hysteretic operation due to the phase transformation is a smoother transition than the reduction in magnetic permeability due to magnetic transition at the Curie temperature. The smoother transition may be easier to control (for example, electrical control using a process control device that interacts with the power supply) than the sharper transition at the Curie temperature. In some embodiments, the Curie temperature is located inside the phase transformation range for selected metallurgies used in temperature limited heaters. This phenomenon provides temperature limited heaters with the smooth transition properties of the phase transformation in addition to a sharp and definite transition due to the reduction in magnetic properties at the Curie temperature. Such temperature limited heaters may be easy to control (due to the phase transformation) while providing finite temperature limits (due to the sharp Curie temperature transition). Using the phase transformation temperature range instead of and/or in addition to the Curie temperature in temperature limited heaters increases the number and range of metallurgies that may be used for temperature limited heaters.

[0601] In certain embodiments, alloy additions are made to the ferromagnetic material to adjust the temperature range of the phase transformation. For example, adding carbon to the ferromagnetic material may increase the phase transformation temperature range and lower the onset temperature of the phase transformation. Adding titanium to the ferromagnetic material may increase the onset temperature of the phase transformation and decrease the phase transformation temperature range. Alloy compositions may be adjusted to provide desired Curie temperature and phase transformation properties for the ferromagnetic material. The alloy composition of the ferromagnetic material may be chosen based on desired properties for the ferromagnetic material (such as, but not limited to, magnetic permeability transition temperature or temperature range, resistance versus temperature profile, or power output). Addition of titanium may allow higher Curie temperatures to be obtained when adding cobalt to 410 stainless steel by raising the ferrite to austenite phase transformation temperature range to a temperature range that is above, or well above, the Curie temperature of the ferromagnetic material.

[0602] In some embodiments, temperature limited heaters are more economical to manufacture or make than standard heaters. Typical ferromagnetic materials include iron, carbon steel, or ferritic stainless steel. Such materials are inexpensive as compared to nickel-based heating alloys (such as nichrome, Kanthal™ (Bulten-Kanthal AB, Sweden), and/or LOHM™ (Driver-Harris Company, Harrison, New Jersey, U.S.A.)) typically used in insulated conductor (mineral insulated cable) heaters. In one embodiment of the temperature limited heater, the temperature limited heater is manufactured in continuous lengths as an insulated conductor heater to lower costs and improve reliability.

[0603] In some embodiments, the temperature limited heater is placed in the heater well using a coiled tubing rig. A heater that can be coiled on a spool may be manufactured by using metal such as ferritic stainless steel (for example, 409 stainless steel) that is welded using electrical resistance welding (ERW). U.S. Patent 7,032,809 to Hopkins describes forming seam-welded pipe. To form a heater section, a metal strip from a roll is passed through a former where it is shaped into a tubular and then longitudinally welded using ERW.

[0604] In some embodiments, a composite tubular may be formed from the seam-welded tubular. The seam-welded tubular is passed through a second former where a conductive strip (for example, a copper strip) is applied, drawn down tightly on the tubular through a die, and longitudinally welded using ERW. A sheath may be formed by longitudinally welding a support material (for example, steel such as 347H or 347HH) over the conductive strip material. The support material may be a strip rolled over the conductive strip material. An overburden section of the heater may be formed in a similar manner.

[0605] In certain embodiments, the overburden section uses a non-ferromagnetic material such as 304 stainless steel or 316 stainless steel instead of a ferromagnetic material. The heater section and overburden section may be coupled using standard techniques such as butt welding using an orbital welder. In some embodiments, the overburden section material (the non-ferromagnetic material) may be pre-welded to the ferromagnetic material before rolling. The pre-welding may eliminate the need for a separate coupling step (for example, butt welding). In an embodiment, a flexible cable (for example, a furnace cable such as a MGT 1000 furnace cable) may be pulled through the center after forming the tubular heater. An end bushing on the flexible cable may be welded to the tubular heater to provide an electrical current return path. The tubular heater, including the flexible cable, may be coiled onto a spool before installation into a heater well. In an embodiment, the temperature limited heater is installed using the coiled tubing rig. The coiled tubing rig may place the temperature limited heater in a deformation resistant container in the formation. The deformation resistant container may be placed in the heater well using conventional methods.

[0606] Temperature limited heaters may be used for heating hydrocarbon formations including, but not limited to, oil shale formations, coal formations, tar sands formations, and formations with heavy viscous oils. Temperature limited heaters may also be used in the field of environmental remediation to vaporize or destroy soil contaminants. Embodiments of temperature limited heaters may be used to heat fluids in a wellbore or sub-sea pipeline to inhibit deposition of paraffin or various hydrates. In some embodiments, a temperature limited heater is used for solution mining a subsurface formation (for example, an oil shale or a coal formation). In certain embodiments, a fluid (for example, molten salt) is placed in a wellbore and heated with a temperature limited heater to inhibit deformation and/or collapse of the wellbore. In some embodiments, the temperature limited heater is attached to a sucker rod in the wellbore or is part of the sucker rod itself. In some embodiments, temperature limited heaters are used to heat a near wellbore region to reduce near wellbore oil viscosity during production of high viscosity crude oils and during transport of high viscosity oils to the surface. In some embodiments, a temperature limited heater enables gas lifting of a viscous oil by lowering the viscosity of the oil without coking the oil. Temperature limited heaters may be used in sulfur transfer lines to maintain temperatures between about 110 °C and about 130 °C.

[0607] The ferromagnetic alloy or ferromagnetic alloys used in the temperature limited heater determine the Curie temperature of the heater. Curie temperature data for various metals is listed in "American Institute of Physics Handbook," Second Edition, McGraw-Hill, pages 5-170 through 5-176. Ferromagnetic conductors may include one or more of the ferromagnetic elements (iron, cobalt, and nickel) and/or alloys of these elements. In some embodiments, ferromagnetic conductors include iron-chromium (Fe-Cr) alloys that contain tungsten (W) (for example, HCM12A and SAVE12 (Sumitomo Metals Co., Japan) and/or iron alloys that contain chromium (for example, Fe-Cr alloys, Fe-Cr-W alloys, Fe-Cr-V (vanadium) alloys, and Fe-Cr-Nb (Niobium) alloys). Of the three main ferromagnetic elements, iron has a Curie temperature of approximately 770 °C; cobalt (Co) has a Curie temperature of approximately 1131 °C; and nickel has a Curie temperature of approximately 358 °C. An iron-cobalt alloy has a Curie temperature higher than the Curie temperature of iron. For example, iron-cobalt alloy with 2% by weight cobalt has a Curie temperature of approximately 800 °C; iron-cobalt alloy with 12% by weight cobalt has a Curie temperature of approximately 900 °C; and iron-cobalt alloy with 20% by weight cobalt has a Curie temperature of approximately 950 °C. Iron-nickel alloy has a Curie temperature lower than the Curie temperature of iron. For example, iron-nickel alloy with 20% by weight nickel has a Curie temperature of approximately 720 °C, and iron-nickel alloy with 60% by weight nickel has a Curie temperature of approximately 560 °C.

[0608] Some non-ferromagnetic elements used as alloys raise the Curie temperature of iron. For example, an iron-vanadium alloy with 5.9% by weight vanadium has a Curie temperature of approximately 815 °C. Other non-ferromagnetic elements (for example, carbon, aluminum, copper, silicon, and/or chromium) may be alloyed with iron or other ferromagnetic materials to lower the Curie temperature. Non-ferromagnetic materials that raise the Curie temperature may be combined with non-ferromagnetic materials that lower the Curie temperature and alloyed with iron or other ferromagnetic materials to produce a material with a desired Curie temperature and other desired physical and/or chemical properties. In some embodiments, the Curie temperature material is a ferrite such as $NiFe_2O_4$. In other embodiments, the Curie temperature material is a binary compound such as $FeNi_3$ or Fe_3Al.

[0609] In some embodiments, the improved alloy includes carbon, cobalt, iron, manganese, silicon, or mixtures thereof. In certain embodiments, the improved alloy includes, by weight: about 0.1% to about 10% cobalt; about 0.1% carbon, about 0.5% manganese, about 0.5% silicon, with the balance being iron. In certain embodiments, the improved alloy includes, by weight: about 0.1% to about 10% cobalt; about 0.1% carbon, about 0.5% manganese, about 0.5% silicon, with the balance being iron.

[0610] In some embodiments, the improved alloy includes chromium, carbon, cobalt, iron, manganese, silicon, titanium, vanadium, or mixtures thereof. In certain embodiments, the improved alloy includes, by weight: about 5% to about 20% cobalt, about 0.1% carbon, about 0.5% manganese, about 0.5% silicon, about 0.1% to about 2% vanadium with the balance being iron. In some embodiments, the improved alloy includes, by weight: about 12% chromium, about 0.1% carbon, about 0.5% silicon, about 0.1% to about 0.5% manganese, above 0% to about 15% cobalt, above 0% to about 2% vanadium, above 0% to about 1% titanium, with the balance being iron. In some embodiments, the improved alloy includes, by weight: about 12% chromium, about 0.1% carbon, about 0.5% silicon, about 0.1% to about 0.5% manganese, above 0% to about 2% vanadium, above 0% to about 1% titanium, with the balance being iron. In some embodiments, the improved alloy includes, by weight: about 12% chromium, about 0.1% carbon, about 0.5% silicon, about 0.1% to about 0.5% manganese, above 0% to about 2% vanadium, with the balance being iron. In certain embodiments, the improved alloy includes, by weight: about 12% chromium, about 0.1% carbon, about 0.5% silicon, about 0.1% to about 0.5% manganese, above 0% to about 15% cobalt, above 0% to about 1% titanium, with the balance being iron. In certain embodiments, the improved alloy includes, by weight: about 12% chromium, about 0.1% carbon, about 0.5% silicon, about 0.1% to about 0.5% manganese, above 0% to about 15% cobalt, with the balance being iron. The addition of vanadium may allow for use of higher amounts of cobalt in the improved alloy.

[0611] Certain embodiments of temperature limited heaters may include more than one ferromagnetic material. Such embodiments are within the scope of embodiments described herein if any conditions described herein apply to at least one of the ferromagnetic materials in the temperature limited heater.

[0612] Ferromagnetic properties generally decay as the Curie temperature and/or the phase transformation temperature range is approached. The "Handbook of Electrical Heating for Industry" by C. James Erickson (IEEE Press, 1995) shows a typical curve for 1% carbon steel (steel with 1% carbon by weight). The loss of magnetic permeability starts at temperatures above 650 °C and tends to be complete when temperatures exceed 730 °C. Thus, the self-limiting temperature may be somewhat below the actual Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. The skin depth for current flow in 1% carbon steel is 0.132 cm at room temperature and increases to 0.445 cm at 720 °C. From 720 °C to 730 °C, the skin depth sharply increases to over 2.5 cm. Thus, a temperature limited heater embodiment using 1% carbon steel begins to self-limit between 650 °C and 730 °C.

[0613] Skin depth generally defines an effective penetration depth of time-varying current into the conductive material. In general, current density decreases exponentially with distance from an outer surface to the center along the radius of the conductor. The depth at which the current density is approximately 1/e of the surface current density is called the skin depth. For a solid cylindrical rod with a diameter much greater than the penetration depth, or for hollow cylinders with a wall thickness exceeding the penetration depth, the skin depth, δ, is:

$$\text{(EQN. 2)} \qquad \delta = 1981.5 * (\rho/(\mu * f))^{1/2};$$

in which: δ = skin depth in inches;

ρ = resistivity at operating temperature (ohm-cm);

μ = relative magnetic permeability; and

f = frequency (Hz).

EQN. 2 is obtained from "Handbook of Electrical Heating for Industry" by C. James Erickson (IEEE Press, 1995). For most metals, resistivity (ρ) increases with temperature. The relative magnetic permeability generally varies with temperature and with current. Additional equations may be used to assess the variance of magnetic permeability and/or skin depth on both temperature and/or current. The dependence of μ on current arises from the dependence of μ on the electromagnetic field.

[0614] Materials used in the temperature limited heater may be selected to provide a desired turndown ratio. Turndown ratios of at least 1.1:1, 2:1, 3:1, 4:1, 5:1, 10:1, 30:1, or 50:1 may be selected for temperature limited heaters. Larger turndown ratios may also be used. A selected

turndown ratio may depend on a number of factors including, but not limited to, the type of formation in which the temperature limited heater is located (for example, a higher turndown ratio may be used for an oil shale formation with large variations in thermal conductivity between rich and lean oil shale layers) and/or a temperature limit of materials used in the wellbore (for example, temperature limits of heater materials). In some embodiments, the turndown ratio is increased by coupling additional copper or another good electrical conductor to the ferromagnetic material (for example, adding copper to lower the resistance above the Curie temperature and/or the phase transformation temperature range).

[0615] The temperature limited heater may provide a maximum heat output (power output) below the Curie temperature and/or the phase transformation temperature range of the heater. In certain embodiments, the maximum heat output is at least 400 W/m (Watts per meter), 600 W/m, 700 W/m, 800 W/m, or higher up to 2000 W/m. The temperature limited heater reduces the amount of heat output by a section of the heater when the temperature of the section of the heater approaches or is above the Curie temperature and/or the phase transformation temperature range. The reduced amount of heat may be substantially less than the heat output below the Curie temperature and/or the phase transformation temperature range. In some embodiments, the reduced amount of heat is at most 400 W/m, 200 W/m, 100 W/m or may approach 0 W/m.

[0616] In certain embodiments, the temperature limited heater operates substantially independently of the thermal load on the heater in a certain operating temperature range. "Thermal load" is the rate that heat is transferred from a heating system to its surroundings. It is to be understood that the thermal load may vary with temperature of the surroundings and/or the thermal conductivity of the surroundings. In an embodiment, the temperature limited heater operates at or above the Curie temperature and/or the phase transformation temperature range of the temperature limited heater such that the operating temperature of the heater increases at most by 3 °C, 2 °C, 1.5 °C, 1 °C, or 0.5 °C for a decrease in thermal load of 1 W/m proximate to a portion of the heater. In certain embodiments, the temperature limited heater operates in such a manner at a relatively constant current.

[0617] The AC or modulated DC resistance and/or the heat output of the temperature limited heater may decrease as the temperature approaches the Curie temperature and/or the phase transformation temperature range and decrease sharply near or above the Curie temperature due to the Curie effect and/or phase transformation effect. In certain embodiments, the value of the electrical resistance or heat output above or near the Curie temperature and/or the phase transformation temperature range is at most one-half of the value of electrical resistance or heat output at a certain point below the Curie temperature and/or the phase transformation temperature range. In some embodiments, the heat output above or near the Curie temperature

and/or the phase transformation temperature range is at most 90%, 70%, 50%, 30%, 20%, 10%, or less (down to 1%) of the heat output at a certain point below the Curie temperature and/or the phase transformation temperature range (for example, 30 °C below the Curie temperature, 40 °C below the Curie temperature, 50 °C below the Curie temperature, or 100 °C below the Curie temperature). In certain embodiments, the electrical resistance above or near the Curie temperature and/or the phase transformation temperature range decreases to 80%, 70%, 60%, 50%, or less (down to 1%) of the electrical resistance at a certain point below the Curie temperature and/or the phase transformation temperature range (for example, 30 °C below the Curie temperature, 40 °C below the Curie temperature, 50 °C below the Curie temperature, or 100 °C below the Curie temperature).

[0618] In some embodiments, AC frequency is adjusted to change the skin depth of the ferromagnetic material. For example, the skin depth of 1% carbon steel at room temperature is 0.132 cm at 60 Hz, 0.0762 cm at 180 Hz, and 0.046 cm at 440 Hz. Since heater diameter is typically larger than twice the skin depth, using a higher frequency (and thus a heater with a smaller diameter) reduces heater costs. For a fixed geometry, the higher frequency results in a higher turndown ratio. The turndown ratio at a higher frequency is calculated by multiplying the turndown ratio at a lower frequency by the square root of the higher frequency divided by the lower frequency. In some embodiments, a frequency between 100 Hz and 1000 Hz, between 140 Hz and 200 Hz, or between 400 Hz and 600 Hz is used (for example, 180 Hz, 540 Hz, or 720 Hz). In some embodiments, high frequencies may be used. The frequencies may be greater than 1000 Hz.

[0619] To maintain a substantially constant skin depth until the Curie temperature and/or the phase transformation temperature range of the temperature limited heater is reached, the heater may be operated at a lower frequency when the heater is cold and operated at a higher frequency when the heater is hot. Line frequency heating is generally favorable, however, because there is less need for expensive components such as power supplies, transformers, or current modulators that alter frequency. Line frequency is the frequency of a general supply of current. Line frequency is typically 60 Hz, but may be 50 Hz or another frequency depending on the source for the supply of the current. Higher frequencies may be produced using commercially available equipment such as solid state variable frequency power supplies. Transformers that convert three-phase power to single-phase power with three times the frequency are commercially available. For example, high voltage three-phase power at 60 Hz may be transformed to single-phase power at 180 Hz and at a lower voltage. Such transformers are less expensive and more energy efficient than solid state variable frequency power supplies. In certain embodiments,

transformers that convert three-phase power to single-phase power are used to increase the frequency of power supplied to the temperature limited heater.

[0620] In certain embodiments, modulated DC (for example, chopped DC, waveform modulated DC, or cycled DC) may be used for providing electrical power to the temperature limited heater. A DC modulator or DC chopper may be coupled to a DC power supply to provide an output of modulated direct current. In some embodiments, the DC power supply may include means for modulating DC. One example of a DC modulator is a DC-to-DC converter system. DC-to-DC converter systems are generally known in the art. DC is typically modulated or chopped into a desired waveform. Waveforms for DC modulation include, but are not limited to, square-wave, sinusoidal, deformed sinusoidal, deformed square-wave, triangular, and other regular or irregular waveforms.

[0621] The modulated DC waveform generally defines the frequency of the modulated DC. Thus, the modulated DC waveform may be selected to provide a desired modulated DC frequency. The shape and/or the rate of modulation (such as the rate of chopping) of the modulated DC waveform may be varied to vary the modulated DC frequency. DC may be modulated at frequencies that are higher than generally available AC frequencies. For example, modulated DC may be provided at frequencies of at least 1000 Hz. Increasing the frequency of supplied current to higher values advantageously increases the turndown ratio of the temperature limited heater.

[0622] In certain embodiments, the modulated DC waveform is adjusted or altered to vary the modulated DC frequency. The DC modulator may be able to adjust or alter the modulated DC waveform at any time during use of the temperature limited heater and at high currents or voltages. Thus, modulated DC provided to the temperature limited heater is not limited to a single frequency or even a small set of frequency values. Waveform selection using the DC modulator typically allows for a wide range of modulated DC frequencies and for discrete control of the modulated DC frequency. Thus, the modulated DC frequency is more easily set at a distinct value whereas AC frequency is generally limited to multiples of the line frequency. Discrete control of the modulated DC frequency allows for more selective control over the turndown ratio of the temperature limited heater. Being able to selectively control the turndown ratio of the temperature limited heater allows for a broader range of materials to be used in designing and constructing the temperature limited heater.

[0623] In some embodiments, the modulated DC frequency or the AC frequency is adjusted to compensate for changes in properties (for example, subsurface conditions such as temperature or pressure) of the temperature limited heater during use. The modulated DC frequency or the AC frequency provided to the temperature limited heater is varied based on assessed downhole

conditions. For example, as the temperature of the temperature limited heater in the wellbore increases, it may be advantageous to increase the frequency of the current provided to the heater, thus increasing the turndown ratio of the heater. In an embodiment, the downhole temperature of the temperature limited heater in the wellbore is assessed.

[0624] In certain embodiments, the modulated DC frequency, or the AC frequency, is varied to adjust the turndown ratio of the temperature limited heater. The turndown ratio may be adjusted to compensate for hot spots occurring along a length of the temperature limited heater. For example, the turndown ratio is increased because the temperature limited heater is getting too hot in certain locations. In some embodiments, the modulated DC frequency, or the AC frequency, are varied to adjust a turndown ratio without assessing a subsurface condition.

[0625] At or near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic material, a relatively small change in voltage may cause a relatively large change in current to the load. The relatively small change in voltage may produce problems in the power supplied to the temperature limited heater, especially at or near the Curie temperature and/or the phase transformation temperature range. The problems include, but are not limited to, reducing the power factor, tripping a circuit breaker, and/or blowing a fuse. In some cases, voltage changes may be caused by a change in the load of the temperature limited heater. In certain embodiments, an electrical current supply (for example, a supply of modulated DC or AC) provides a relatively constant amount of current that does not substantially vary with changes in load of the temperature limited heater. In an embodiment, the electrical current supply provides an amount of electrical current that remains within 15%, within 10%, within 5%, or within 2% of a selected constant current value when a load of the temperature limited heater changes.

[0626] Temperature limited heaters may generate an inductive load. The inductive load is due to some applied electrical current being used by the ferromagnetic material to generate a magnetic field in addition to generating a resistive heat output. As downhole temperature changes in the temperature limited heater, the inductive load of the heater changes due to changes in the ferromagnetic properties of ferromagnetic materials in the heater with temperature. The inductive load of the temperature limited heater may cause a phase shift between the current and the voltage applied to the heater.

[0627] A reduction in actual power applied to the temperature limited heater may be caused by a time lag in the current waveform (for example, the current has a phase shift relative to the voltage due to an inductive load) and/or by distortions in the current waveform (for example, distortions in the current waveform caused by introduced harmonics due to a non-linear load). Thus, it may take more current to apply a selected amount of power due to phase shifting or waveform distortion. The ratio of actual power applied and the apparent power that would have been

transmitted if the same current were in phase and undistorted is the power factor. The power factor is always less than or equal to 1. The power factor is 1 when there is no phase shift or distortion in the waveform.

[0628] Actual power applied to a heater due to a phase shift may be described by EQN. 3:

(EQN. 3) $P = I \times V \times \cos(\theta)$;

in which P is the actual power applied to a heater; I is the applied current; V is the applied voltage; and θ is the phase angle difference between voltage and current. Other phenomena such as waveform distortion may contribute to further lowering of the power factor. If there is no distortion in the waveform, then $\cos(\theta)$ is equal to the power factor.

[0629] In certain embodiments, the temperature limited heater includes an inner conductor inside an outer conductor. The inner conductor and the outer conductor are radially disposed about a central axis. The inner and outer conductors may be separated by an insulation layer. In certain embodiments, the inner and outer conductors are coupled at the bottom of the temperature limited heater. Electrical current may flow into the temperature limited heater through the inner conductor and return through the outer conductor. One or both conductors may include ferromagnetic material.

[0630] The insulation layer may include an electrically insulating ceramic with high thermal conductivity, such as magnesium oxide, aluminum oxide, silicon dioxide, beryllium oxide, boron nitride, silicon nitride, or combinations thereof. The insulating layer may be a compacted powder (for example, compacted ceramic powder). Compaction may improve thermal conductivity and provide better insulation resistance. For lower temperature applications, polymer insulation made from, for example, fluoropolymers, polyimides, polyamides, and/or polyethylenes, may be used. In some embodiments, the polymer insulation is made of perfluoroalkoxy (PFA) or polyetheretherketone (PEEK™ (Victrex Ltd., England)). The insulating layer may be chosen to be substantially infrared transparent to aid heat transfer from the inner conductor to the outer conductor. In an embodiment, the insulating layer is transparent quartz sand. The insulation layer may be air or a non-reactive gas such as helium, nitrogen, or sulfur hexafluoride. If the insulation layer is air or a non-reactive gas, there may be insulating spacers designed to inhibit electrical contact between the inner conductor and the outer conductor. The insulating spacers may be made of, for example, high purity aluminum oxide or another thermally conducting, electrically insulating material such as silicon nitride. The insulating spacers may be a fibrous ceramic material such as Nextel™ 312 (3M Corporation, St. Paul, Minnesota, U.S.A.), mica tape, or glass fiber. Ceramic material may be made of alumina, alumina-silicate, alumina-borosilicate, silicon nitride, boron nitride, or other materials.

[0631] The insulation layer may be flexible and/or substantially deformation tolerant. For example, if the insulation layer is a solid or compacted material that substantially fills the space between the inner and outer conductors, the temperature limited heater may be flexible and/or substantially deformation tolerant. Forces on the outer conductor can be transmitted through the insulation layer to the solid inner conductor, which may resist crushing. Such a temperature limited heater may be bent, dog-legged, and spiraled without causing the outer conductor and the inner conductor to electrically short to each other. Deformation tolerance may be important if the wellbore is likely to undergo substantial deformation during heating of the formation.

[0632] In certain embodiments, an outermost layer of the temperature limited heater (for example, the outer conductor) is chosen for corrosion resistance, yield strength, and/or creep resistance. In one embodiment, austenitic (non-ferromagnetic) stainless steels such as 201, 304H, 347H, 347HH, 316H, 310H, 347HP, NF709 (Nippon Steel Corp., Japan) stainless steels, or combinations thereof may be used in the outer conductor. The outermost layer may also include a clad conductor. For example, a corrosion resistant alloy such as 800H or 347H stainless steel may be clad for corrosion protection over a ferromagnetic carbon steel tubular. If high temperature strength is not required, the outermost layer may be constructed from ferromagnetic metal with good corrosion resistance such as one of the ferritic stainless steels. In one embodiment, a ferritic alloy of 82.3% by weight iron with 17.7% by weight chromium (Curie temperature of 678 °C) provides desired corrosion resistance.

[0633] The Metals Handbook, vol. 8, page 291 (American Society of Materials (ASM)) includes a graph of Curie temperature of iron-chromium alloys versus the amount of chromium in the alloys. In some temperature limited heater embodiments, a separate support rod or tubular (made from 347H stainless steel) is coupled to the temperature limited heater made from an iron-chromium alloy to provide yield strength and/or creep resistance. In certain embodiments, the support material and/or the ferromagnetic material is selected to provide a 100,000 hour creep-rupture strength of at least 20.7 MPa at 650 °C. In some embodiments, the 100,000 hour creep-rupture strength is at least 13.8 MPa at 650 °C or at least 6.9 MPa at 650 °C. For example, 347H steel has a favorable creep-rupture strength at or above 650 °C. In some embodiments, the 100,000 hour creep-rupture strength ranges from 6.9 MPa to 41.3 MPa or more for longer heaters and/or higher earth or fluid stresses.

[0634] In temperature limited heater embodiments with both an inner ferromagnetic conductor and an outer ferromagnetic conductor, the skin effect current path occurs on the outside of the inner conductor and on the inside of the outer conductor. Thus, the outside of the outer conductor may be clad with the corrosion resistant alloy, such as stainless steel, without affecting the skin effect current path on the inside of the outer conductor.

[0635] A ferromagnetic conductor with a thickness of at least the skin depth at the Curie temperature and/or the phase transformation temperature range allows a substantial decrease in resistance of the ferromagnetic material as the skin depth increases sharply near the Curie temperature and/or the phase transformation temperature range. In certain embodiments when the ferromagnetic conductor is not clad with a highly conducting material such as copper, the thickness of the conductor may be 1.5 times the skin depth near the Curie temperature and/or the phase transformation temperature range, 3 times the skin depth near the Curie temperature and/or the phase transformation temperature range, or even 10 or more times the skin depth near the Curie temperature and/or the phase transformation temperature range. If the ferromagnetic conductor is clad with copper, thickness of the ferromagnetic conductor may be substantially the same as the skin depth near the Curie temperature and/or the phase transformation temperature range. In some embodiments, the ferromagnetic conductor clad with copper has a thickness of at least three-fourths of the skin depth near the Curie temperature and/or the phase transformation temperature range.

[0636] In certain embodiments, the temperature limited heater includes a composite conductor with a ferromagnetic tubular and a non-ferromagnetic, high electrical conductivity core. The non-ferromagnetic, high electrical conductivity core reduces a required diameter of the conductor. For example, the conductor may be composite 1.19 cm diameter conductor with a core of 0.575 cm diameter copper clad with a 0.298 cm thickness of ferritic stainless steel or carbon steel surrounding the core. The core or non-ferromagnetic conductor may be copper or copper alloy. The core or non-ferromagnetic conductor may also be made of other metals that exhibit low electrical resistivity and relative magnetic permeabilities near 1 (for example, substantially non-ferromagnetic materials such as aluminum and aluminum alloys, phosphor bronze, beryllium copper, and/or brass). A composite conductor allows the electrical resistance of the temperature limited heater to decrease more steeply near the Curie temperature and/or the phase transformation temperature range. As the skin depth increases near the Curie temperature and/or the phase transformation temperature range to include the copper core, the electrical resistance decreases very sharply.

[0637] The composite conductor may increase the conductivity of the temperature limited heater and/or allow the heater to operate at lower voltages. In an embodiment, the composite conductor exhibits a relatively flat resistance versus temperature profile at temperatures below a region near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor of the composite conductor. In some embodiments, the temperature limited heater exhibits a relatively flat resistance versus temperature profile between 100 °C and 750 °C or between 300 °C and 600 °C. The relatively flat resistance versus temperature profile may also be

exhibited in other temperature ranges by adjusting, for example, materials and/or the configuration of materials in the temperature limited heater. In certain embodiments, the relative thickness of each material in the composite conductor is selected to produce a desired resistivity versus temperature profile for the temperature limited heater.

[0638] In certain embodiments, the relative thickness of each material in a composite conductor is selected to produce a desired resistivity versus temperature profile for a temperature limited heater. In an embodiment, the composite conductor is an inner conductor surrounded by 0.127 cm thick magnesium oxide powder as an insulator. The outer conductor may be 304H stainless steel with a wall thickness of 0.127 cm. The outside diameter of the heater may be about 1.65 cm.

[0639] A composite conductor (for example, a composite inner conductor or a composite outer conductor) may be manufactured by methods including, but not limited to, coextrusion, roll forming, tight fit tubing (for example, cooling the inner member and heating the outer member, then inserting the inner member in the outer member, followed by a drawing operation and/or allowing the system to cool), explosive or electromagnetic cladding, arc overlay welding, longitudinal strip welding, plasma powder welding, billet coextrusion, electroplating, drawing, sputtering, plasma deposition, coextrusion casting, magnetic forming, molten cylinder casting (of inner core material inside the outer or vice versa), insertion followed by welding or high temperature braising, shielded active gas welding (SAG), and/or insertion of an inner pipe in an outer pipe followed by mechanical expansion of the inner pipe by hydroforming or use of a pig to expand and swage the inner pipe against the outer pipe. In some embodiments, a ferromagnetic conductor is braided over a non-ferromagnetic conductor. In certain embodiments, composite conductors are formed using methods similar to those used for cladding (for example, cladding copper to steel). A metallurgical bond between copper cladding and base ferromagnetic material may be advantageous. Composite conductors produced by a coextrusion process that forms a good metallurgical bond (for example, a good bond between copper and 446 stainless steel) may be provided by Anomet Products, Inc. (Shrewsbury, Massachusetts, U.S.A.).

[0640] In certain embodiments, it may be desirable to form a composite conductor by various methods including longitudinal strip welding. In some embodiments, however, it may be difficult to use longitudinal strip welding techniques if the desired thickness of a layer of a first material has such a large thickness, in relation to the inner core/layer onto which such layer is to be bended, that it does not effectively and/or efficiently bend around an inner core or layer that is made of a second material. In such circumstances, it may be beneficial to use multiple thinner layers of the first material in the longitudinal strip welding process such that the multiple thinner layers can more readily be employed in a longitudinal strip welding process and coupled together

to form a composite of the first material with the desired thickness. So, for example, a first layer of the first material may be bent around an inner core or layer of second material, and then a second layer of the first material may be bent around the first layer of the first material, with the thicknesses of the first and second layers being such that the first and second layers will readily bend around the inner core or layer in a longitudinal strip welding process. Thus, the two layers of the first material may together form the total desired thickness of the first material.

[0641] FIGS. 12-29 depict various embodiments of temperature limited heaters. One or more features of an embodiment of the temperature limited heater depicted in any of these figures may be combined with one or more features of other embodiments of temperature limited heaters depicted in these figures. In certain embodiments described herein, temperature limited heaters are dimensioned to operate at a frequency of 60 Hz AC. It is to be understood that dimensions of the temperature limited heater may be adjusted from those described herein to operate in a similar manner at other AC frequencies or with modulated DC current.

[0642] The temperature limited heaters may be used in conductor-in-conduit heaters. In some embodiments of conductor-in-conduit heaters, the majority of the resistive heat is generated in the conductor, and the heat radiatively, conductively and/or convectively transfers to the conduit. In some embodiments of conductor-in-conduit heaters, the majority of the resistive heat is generated in the conduit.

[0643] FIG. 12 depicts a cross-sectional representation of an embodiment of the temperature limited heater with an outer conductor having a ferromagnetic section and a non-ferromagnetic section. FIGS. 13 and 14 depict transverse cross-sectional views of the embodiment shown in FIG. 12. In one embodiment, ferromagnetic section 358 is used to provide heat to hydrocarbon layers in the formation. Non-ferromagnetic section 360 is used in the overburden of the formation. Non-ferromagnetic section 360 provides little or no heat to the overburden, thus inhibiting heat losses in the overburden and improving heater efficiency. Ferromagnetic section 358 includes a ferromagnetic material such as 409 stainless steel or 410 stainless steel. Ferromagnetic section 358 has a thickness of 0.3 cm. Non-ferromagnetic section 360 is copper with a thickness of 0.3 cm. Inner conductor 362 is copper. Inner conductor 362 has a diameter of 0.9 cm. Electrical insulator 364 is silicon nitride, boron nitride, magnesium oxide powder, or another suitable insulator material. Electrical insulator 364 has a thickness of 0.1 cm to 0.3 cm.

[0644] FIG. 15 depicts a cross-sectional representation of an embodiment of a temperature limited heater with an outer conductor having a ferromagnetic section and a non-ferromagnetic section placed inside a sheath. FIGS. 16, 17, and 18 depict transverse cross-sectional views of the embodiment shown in FIG. 15. Ferromagnetic section 358 is 410 stainless steel with a thickness of 0.6 cm. Non-ferromagnetic section 360 is copper with a thickness of 0.6 cm. Inner

conductor 362 is copper with a diameter of 0.9 cm. Outer conductor 366 includes ferromagnetic material. Outer conductor 366 provides some heat in the overburden section of the heater. Providing some heat in the overburden inhibits condensation or refluxing of fluids in the overburden. Outer conductor 366 is 409, 410, or 446 stainless steel with an outer diameter of 3.0 cm and a thickness of 0.6 cm. Electrical insulator 364 includes compacted magnesium oxide powder with a thickness of 0.3 cm. In some embodiments, electrical insulator 364 includes silicon nitride, boron nitride, or hexagonal type boron nitride. Conductive section 368 may couple inner conductor 362 with ferromagnetic section 358 and/or outer conductor 366.

[0645] FIG. 19A and FIG. 19B depict cross-sectional representations of an embodiment of a temperature limited heater with a ferromagnetic outer conductor. The outer conductor is clad with a conductive layer and a corrosion resistant alloy. Inner conductor 362 is copper. Electrical insulator 364 is silicon nitride, boron nitride, or magnesium oxide. Outer conductor 366 is a 1" Schedule 80 446 stainless steel pipe. Outer conductor 366 is coupled to jacket 370. Jacket 370 is made from corrosion resistant material such as 347H stainless steel. In an embodiment, conductive layer 372 is placed between outer conductor 366 and jacket 370. Conductive layer 372 is a copper layer. Heat is produced primarily in outer conductor 366, resulting in a small temperature differential across electrical insulator 364. Conductive layer 372 allows a sharp decrease in the resistance of outer conductor 366 as the outer conductor approaches the Curie temperature and/or the phase transformation temperature range. Jacket 370 provides protection from corrosive fluids in the wellbore.

[0646] In certain embodiments, inner conductor 362 includes a core of copper or another non-ferromagnetic conductor surrounded by ferromagnetic material (for example, a low Curie temperature material such as Invar 36). In certain embodiments, the copper core has an outer diameter between about 0.125" and about 0.375" (for example, about 0.5") and the ferromagnetic material has an outer diameter between about 0.625" and about 1" (for example, about 0.75"). The copper core may increase the turndown ratio of the heater and/or reduce the thickness needed in the ferromagnetic material, which may allow a lower cost heater to be made. Electrical insulator 364 may be magnesium oxide with an outer diameter between about 1" and about 1.2" (for example, about 1.11"). Outer conductor 366 may include non-ferromagnetic electrically conductive material with high mechanical strength such as 825 stainless steel. Outer conductor 366 may have an outer diameter between about 1.2" and about 1.5" (for example, about 1.33"). In certain embodiments, inner conductor 362 is a forward current path and outer conductor 366 is a return current path. Conductive layer 372 may include copper or another non-ferromagnetic material with an outer diameter between about 1.3" and about 1.4" (for example, about 1.384"). Conductive layer 372 may decrease the resistance of the return current path (to reduce the heat

output of the return path such that little or no heat is generated in the return path) and/or increase the turndown ratio of the heater. Conductive layer 372 may reduce the thickness needed in outer conductor 366 and/or jacket 370, which may allow a lower cost heater to be made. Jacket 370 may include ferromagnetic material such as carbon steel or 410 stainless steel with an outer diameter between about 1.6" and about 1.8" (for example, about 1.684"). Jacket 370 may have a thickness of at least 2 times the skin depth of the ferromagnetic material in the jacket. Jacket 370 may provide protection from corrosive fluids in the wellbore. In some embodiments, inner conductor 362, electrical insulator 364, and outer conductor 366 are formed as composite heater (for example, an insulated conductor heater) and conductive layer 372 and jacket 370 are formed around (for example, wrapped) the composite heater and welded together to form the larger heater embodiment described herein.

[0647] In certain embodiments, jacket 370 includes ferromagnetic material that has a higher Curie temperature than ferromagnetic material in inner conductor 362. Such a temperature limited heater may "contain" current such that the current does not easily flow from the heater to the surrounding formation and/or to any surrounding fluids (for example, production fluids, formation fluids, brine, groundwater, or formation water). In this embodiment, a majority of the current flows through inner conductor 362 until the Curie temperature of the ferromagnetic material in the inner conductor is reached. After the Curie temperature of ferromagnetic material in inner conductor 362 is reached, a majority of the current flows through the core of copper in the inner conductor. The ferromagnetic properties of jacket 370 inhibit the current from flowing outside the jacket and "contain" the current. Such a heater may be used in lower temperature applications where fluids are present such as providing heat in a production wellbore to increase oil production.

[0648] In some embodiments, the conductor (for example, an inner conductor, an outer conductor, or a ferromagnetic conductor) is the composite conductor that includes two or more different materials. In certain embodiments, the composite conductor includes two or more ferromagnetic materials. In some embodiments, the composite ferromagnetic conductor includes two or more radially disposed materials. In certain embodiments, the composite conductor includes a ferromagnetic conductor and a non-ferromagnetic conductor. In some embodiments, the composite conductor includes the ferromagnetic conductor placed over a non-ferromagnetic core. Two or more materials may be used to obtain a relatively flat electrical resistivity versus temperature profile in a temperature region below the Curie temperature, and/or the phase transformation temperature range, and/or a sharp decrease (a high turndown ratio) in the electrical resistivity at or near the Curie temperature and/or the phase transformation temperature

range. In some cases, two or more materials are used to provide more than one Curie temperature and/or phase transformation temperature range for the temperature limited heater.

[0649] The composite electrical conductor may be used as the conductor in any electrical heater embodiment described herein. For example, the composite conductor may be used as the conductor in a conductor-in-conduit heater or an insulated conductor heater. In certain embodiments, the composite conductor may be coupled to a support member such as a support conductor. The support member may be used to provide support to the composite conductor so that the composite conductor is not relied upon for strength at or near the Curie temperature and/or the phase transformation temperature range. The support member may be useful for heaters of lengths of at least 100 m. The support member may be a non-ferromagnetic member that has good high temperature creep strength. Examples of materials that are used for a support member include, but are not limited to, Haynes® 625 alloy and Haynes® HR120® alloy (Haynes International, Kokomo, Indiana, U.S.A.), NF709, Incoloy® 800H alloy and 347HP alloy (Allegheny Ludlum Corp., Pittsburgh, Pennsylvania, U.S.A.). In some embodiments, materials in a composite conductor are directly coupled (for example, brazed, metallurgically bonded, or swaged) to each other and/or the support member. Using a support member may reduce the need for the ferromagnetic member to provide support for the temperature limited heater, especially at or near the Curie temperature and/or the phase transformation temperature range. Thus, the temperature limited heater may be designed with more flexibility in the selection of ferromagnetic materials.

[0650] FIG. 20 depicts a cross-sectional representation of an embodiment of the composite conductor with the support member. Core 374 is surrounded by ferromagnetic conductor 376 and support member 378. In some embodiments, core 374, ferromagnetic conductor 376, and support member 378 are directly coupled (for example, brazed together or metallurgically bonded together). In one embodiment, core 374 is copper, ferromagnetic conductor 376 is 446 stainless steel, and support member 378 is 347H alloy. In certain embodiments, support member 378 is a Schedule 80 pipe. Support member 378 surrounds the composite conductor having ferromagnetic conductor 376 and core 374. Ferromagnetic conductor 376 and core 374 may be joined to form the composite conductor by, for example, a coextrusion process. For example, the composite conductor is a 1.9 cm outside diameter 446 stainless steel ferromagnetic conductor surrounding a 0.95 cm diameter copper core.

[0651] In certain embodiments, the diameter of core 374 is adjusted relative to a constant outside diameter of ferromagnetic conductor 376 to adjust the turndown ratio of the temperature limited heater. For example, the diameter of core 374 may be increased to 1.14 cm while maintaining

the outside diameter of ferromagnetic conductor 376 at 1.9 cm to increase the turndown ratio of the heater.

[0652] FIG. 21 depicts a cross-sectional representation of an embodiment of the composite conductor with support member 378 separating the conductors. In one embodiment, core 374 is copper with a diameter of 0.95 cm, support member 378 is 347H alloy with an outside diameter of 1.9 cm, and ferromagnetic conductor 376 is 446 stainless steel with an outside diameter of 2.7 cm. The support member depicted in FIG. 21 has a lower creep strength relative to the support members depicted in FIG. 20.

[0653] In certain embodiments, support member 378 is located inside the composite conductor. FIG. 22 depicts a cross-sectional representation of an embodiment of the composite conductor surrounding support member 378. Support member 378 is made of 347H alloy. Inner conductor 362 is copper. Ferromagnetic conductor 376 is 446 stainless steel. In one embodiment, support member 378 is 1.25 cm diameter 347H alloy, inner conductor 362 is 1.9 cm outside diameter copper, and ferromagnetic conductor 376 is 2.7 cm outside diameter 446 stainless steel. The turndown ratio is higher than the turndown ratio for the embodiments depicted in FIGS. 20, 21, and 23 for the same outside diameter, but the creep strength is lower.

[0654] In some embodiments, the thickness of inner conductor 362, which is copper, is reduced and the thickness of support member 378 is increased to increase the creep strength at the expense of reduced turndown ratio. For example, the diameter of support member 378 is increased to 1.6 cm while maintaining the outside diameter of inner conductor 362 at 1.9 cm to reduce the thickness of the conduit. This reduction in thickness of inner conductor 362 results in a decreased turndown ratio relative to the thicker inner conductor embodiment but an increased creep strength.

[0655] FIG. 23 depicts a cross-sectional representation of an embodiment of the composite conductor surrounding support member 378. In one embodiment, support member 378 is 347H alloy with a 0.63 cm diameter center hole. In some embodiments, support member 378 is a preformed conduit. In certain embodiments, support member 378 is formed by having a dissolvable material (for example, copper dissolvable by nitric acid) located inside the support member during formation of the composite conductor. The dissolvable material is dissolved to form the hole after the conductor is assembled. In an embodiment, support member 378 is 347H alloy with an inside diameter of 0.63 cm and an outside diameter of 1.6 cm, inner conductor 362 is copper with an outside diameter of 1.8 cm, and ferromagnetic conductor 376 is 446 stainless steel with an outside diameter of 2.7 cm.

[0656] In certain embodiments, the composite electrical conductor is used as the conductor in the conductor-in-conduit heater. For example, the composite electrical conductor may be used as conductor 380 in FIG. 24.

[0657] FIG. 24 depicts a cross-sectional representation of an embodiment of the conductor-in-conduit heater. Conductor 380 is disposed in conduit 382. Conductor 380 is a rod or conduit of electrically conductive material. Low resistance sections 384 are present at both ends of conductor 380 to generate less heating in these sections. Low resistance section 384 is formed by having a greater cross-sectional area of conductor 380 in that section, or the sections are made of material having less resistance. In certain embodiments, low resistance section 384 includes a low resistance conductor coupled to conductor 380.

[0658] Conduit 382 is made of an electrically conductive material. Conduit 382 is disposed in opening 386 in hydrocarbon layer 388. Opening 386 has a diameter that accommodates conduit 382.

[0659] Conductor 380 may be centered in conduit 382 by centralizers 390. Centralizers 390 electrically isolate conductor 380 from conduit 382. Centralizers 390 inhibit movement and properly locate conductor 380 in conduit 382. Centralizers 390 are made of ceramic material or a combination of ceramic and metallic materials. Centralizers 390 inhibit deformation of conductor 380 in conduit 382. Centralizers 390 are touching or spaced at intervals between approximately 0.1 m (meters) and approximately 3 m or more along conductor 380.

[0660] A second low resistance section 384 of conductor 380 may couple conductor 380 to wellhead 392. Electrical current may be applied to conductor 380 from power cable 394 through low resistance section 384 of conductor 380. Electrical current passes from conductor 380 through sliding connector 396 to conduit 382. Conduit 382 may be electrically insulated from overburden casing 398 and from wellhead 392 to return electrical current to power cable 394. Heat may be generated in conductor 380 and conduit 382. The generated heat may radiate in conduit 382 and opening 386 to heat at least a portion of hydrocarbon layer 388.

[0661] Overburden casing 398 may be disposed in overburden 400. In some embodiments, overburden casing 398 is surrounded by materials (for example, reinforcing material and/or cement) that inhibit heating of overburden 400. Low resistance section 384 of conductor 380 may be placed in overburden casing 398. Low resistance section 384 of conductor 380 is made of, for example, carbon steel. Low resistance section 384 of conductor 380 may be centralized in overburden casing 398 using centralizers 390. Centralizers 390 are spaced at intervals of approximately 6 m to approximately 12 m or, for example, approximately 9 m along low resistance section 384 of conductor 380. In a heater embodiment, low resistance sections 384 are coupled to conductor 380 by one or more welds. In other heater embodiments, low resistance

sections are threaded, threaded and welded, or otherwise coupled to the conductor. Low resistance section 384 generates little or no heat in overburden casing 398. Packing 402 may be placed between overburden casing 398 and opening 386. Packing 402 may be used as a cap at the junction of overburden 400 and hydrocarbon layer 388 to allow filling of materials in the annulus between overburden casing 398 and opening 386. In some embodiments, packing 402 inhibits fluid from flowing from opening 386 to surface 404.

[0662] FIG. 25 depicts a cross-sectional representation of an embodiment of a removable conductor-in-conduit heat source. Conduit 382 may be placed in opening 386 through overburden 400 such that a gap remains between the conduit and overburden casing 398. Fluids may be removed from opening 386 through the gap between conduit 382 and overburden casing 398. Fluids may be removed from the gap through conduit 406. Conduit 382 and components of the heat source included in the conduit that are coupled to wellhead 392 may be removed from opening 386 as a single unit. The heat source may be removed as a single unit to be repaired, replaced, and/or used in another portion of the formation.

[0663] For a temperature limited heater in which the ferromagnetic conductor provides a majority of the resistive heat output below the Curie temperature and/or the phase transformation temperature range, a majority of the current flows through material with highly non-linear functions of magnetic field (H) versus magnetic induction (B). These non-linear functions may cause strong inductive effects and distortion that lead to decreased power factor in the temperature limited heater at temperatures below the Curie temperature and/or the phase transformation temperature range. These effects may render the electrical power supply to the temperature limited heater difficult to control and may result in additional current flow through surface and/or overburden power supply conductors. Expensive and/or difficult to implement control systems such as variable capacitors or modulated power supplies may be used to compensate for these effects and to control temperature limited heaters where the majority of the resistive heat output is provided by current flow through the ferromagnetic material.

[0664] In certain temperature limited heater embodiments, the ferromagnetic conductor confines a majority of the flow of electrical current to an electrical conductor coupled to the ferromagnetic conductor when the temperature limited heater is below or near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. The electrical conductor may be a sheath, jacket, support member, corrosion resistant member, or other electrically resistive member. In some embodiments, the ferromagnetic conductor confines a majority of the flow of electrical current to the electrical conductor positioned between an outermost layer and the ferromagnetic conductor. The ferromagnetic conductor is located in the cross section of the temperature limited heater such that the magnetic properties of the ferromagnetic conductor at or

below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor confine the majority of the flow of electrical current to the electrical conductor. The majority of the flow of electrical current is confined to the electrical conductor due to the skin effect of the ferromagnetic conductor. Thus, the majority of the current is flowing through material with substantially linear resistive properties throughout most of the operating range of the heater.

[0665] In certain embodiments, the ferromagnetic conductor and the electrical conductor are located in the cross section of the temperature limited heater so that the skin effect of the ferromagnetic material limits the penetration depth of electrical current in the electrical conductor and the ferromagnetic conductor at temperatures below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. Thus, the electrical conductor provides a majority of the electrically resistive heat output of the temperature limited heater at temperatures up to a temperature at or near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. In certain embodiments, the dimensions of the electrical conductor may be chosen to provide desired heat output characteristics.

[0666] Because the majority of the current flows through the electrical conductor below the Curie temperature and/or the phase transformation temperature range, the temperature limited heater has a resistance versus temperature profile that at least partially reflects the resistance versus temperature profile of the material in the electrical conductor. Thus, the resistance versus temperature profile of the temperature limited heater is substantially linear below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor if the material in the electrical conductor has a substantially linear resistance versus temperature profile. The resistance of the temperature limited heater has little or no dependence on the current flowing through the heater until the temperature nears the Curie temperature and/or the phase transformation temperature range. The majority of the current flows in the electrical conductor rather than the ferromagnetic conductor below the Curie temperature and/or the phase transformation temperature range.

[0667] Resistance versus temperature profiles for temperature limited heaters in which the majority of the current flows in the electrical conductor also tend to exhibit sharper reductions in resistance near or at the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. The sharper reductions in resistance near or at the Curie temperature and/or the phase transformation temperature range are easier to control than more gradual resistance reductions near the Curie temperature and/or the phase transformation temperature range because little current is flowing through the ferromagnetic material.

[0668] In certain embodiments, the material and/or the dimensions of the material in the electrical conductor are selected so that the temperature limited heater has a desired resistance versus temperature profile below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor.

[0669] Temperature limited heaters in which the majority of the current flows in the electrical conductor rather than the ferromagnetic conductor below the Curie temperature and/or the phase transformation temperature range are easier to predict and/or control. Behavior of temperature limited heaters in which the majority of the current flows in the electrical conductor rather than the ferromagnetic conductor below the Curie temperature and/or the phase transformation temperature range may be predicted by, for example, the resistance versus temperature profile and/or the power factor versus temperature profile. Resistance versus temperature profiles and/or power factor versus temperature profiles may be assessed or predicted by, for example, experimental measurements that assess the behavior of the temperature limited heater, analytical equations that assess or predict the behavior of the temperature limited heater, and/or simulations that assess or predict the behavior of the temperature limited heater.

[0670] In certain embodiments, assessed or predicted behavior of the temperature limited heater is used to control the temperature limited heater. The temperature limited heater may be controlled based on measurements (assessments) of the resistance and/or the power factor during operation of the heater. In some embodiments, the power, or current, supplied to the temperature limited heater is controlled based on assessment of the resistance and/or the power factor of the heater during operation of the heater and the comparison of this assessment versus the predicted behavior of the heater. In certain embodiments, the temperature limited heater is controlled without measurement of the temperature of the heater or a temperature near the heater. Controlling the temperature limited heater without temperature measurement eliminates operating costs associated with downhole temperature measurement. Controlling the temperature limited heater based on assessment of the resistance and/or the power factor of the heater also reduces the time for making adjustments in the power or current supplied to the heater compared to controlling the heater based on measured temperature.

[0671] As the temperature of the temperature limited heater approaches or exceeds the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor, reduction in the ferromagnetic properties of the ferromagnetic conductor allows electrical current to flow through a greater portion of the electrically conducting cross section of the temperature limited heater. Thus, the electrical resistance of the temperature limited heater is reduced and the temperature limited heater automatically provides reduced heat output at or near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor.

In certain embodiments, a highly electrically conductive member is coupled to the ferromagnetic conductor and the electrical conductor to reduce the electrical resistance of the temperature limited heater at or above the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. The highly electrically conductive member may be an inner conductor, a core, or another conductive member of copper, aluminum, nickel, or alloys thereof.

[0672] The ferromagnetic conductor that confines the majority of the flow of electrical current to the electrical conductor at temperatures below the Curie temperature and/or the phase transformation temperature range may have a relatively small cross section compared to the ferromagnetic conductor in temperature limited heaters that use the ferromagnetic conductor to provide the majority of resistive heat output up to or near the Curie temperature and/or the phase transformation temperature range. A temperature limited heater that uses the electrical conductor to provide a majority of the resistive heat output below the Curie temperature and/or the phase transformation temperature range has low magnetic inductance at temperatures below the Curie temperature and/or the phase transformation temperature range because less current is flowing through the ferromagnetic conductor as compared to the temperature limited heater where the majority of the resistive heat output below the Curie temperature and/or the phase transformation temperature range is provided by the ferromagnetic material. Magnetic field (H) at radius (r) of the ferromagnetic conductor is proportional to the current (I) flowing through the ferromagnetic conductor and the core divided by the radius, or:

(EQN. 4) $H \propto I/r.$

Since only a portion of the current flows through the ferromagnetic conductor for a temperature limited heater that uses the outer conductor to provide a majority of the resistive heat output below the Curie temperature and/or the phase transformation temperature range, the magnetic field of the temperature limited heater may be significantly smaller than the magnetic field of the temperature limited heater where the majority of the current flows through the ferromagnetic material. The relative magnetic permeability (μ) may be large for small magnetic fields.

[0673] The skin depth (δ) of the ferromagnetic conductor is inversely proportional to the square root of the relative magnetic permeability (μ):

(EQN. 5) $\delta \propto (1/\mu)^{1/2}.$

Increasing the relative magnetic permeability decreases the skin depth of the ferromagnetic conductor. However, because only a portion of the current flows through the ferromagnetic conductor for temperatures below the Curie temperature and/or the phase transformation temperature range, the radius (or thickness) of the ferromagnetic conductor may be decreased for ferromagnetic materials with large relative magnetic permeabilities to compensate for the

decreased skin depth while still allowing the skin effect to limit the penetration depth of the electrical current to the electrical conductor at temperatures below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. The radius (thickness) of the ferromagnetic conductor may be between 0.3 mm and 8 mm, between 0.3 mm and 2 mm, or between 2 mm and 4 mm depending on the relative magnetic permeability of the ferromagnetic conductor. Decreasing the thickness of the ferromagnetic conductor decreases costs of manufacturing the temperature limited heater, as the cost of ferromagnetic material tends to be a significant portion of the cost of the temperature limited heater. Increasing the relative magnetic permeability of the ferromagnetic conductor provides a higher turndown ratio and a sharper decrease in electrical resistance for the temperature limited heater at or near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor.

[0674] Ferromagnetic materials (such as purified iron or iron-cobalt alloys) with high relative magnetic permeabilities (for example, at least 200, at least 1000, at least 1×10^4, or at least 1×10^5) and/or high Curie temperatures (for example, at least 600 °C, at least 700 °C, or at least 800 °C) tend to have less corrosion resistance and/or less mechanical strength at high temperatures. The electrical conductor may provide corrosion resistance and/or high mechanical strength at high temperatures for the temperature limited heater. Thus, the ferromagnetic conductor may be chosen primarily for its ferromagnetic properties.

[0675] Confining the majority of the flow of electrical current to the electrical conductor below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor reduces variations in the power factor. Because only a portion of the electrical current flows through the ferromagnetic conductor below the Curie temperature and/or the phase transformation temperature range, the non-linear ferromagnetic properties of the ferromagnetic conductor have little or no effect on the power factor of the temperature limited heater, except at or near the Curie temperature and/or the phase transformation temperature range. Even at or near the Curie temperature and/or the phase transformation temperature range, the effect on the power factor is reduced compared to temperature limited heaters in which the ferromagnetic conductor provides a majority of the resistive heat output below the Curie temperature and/or the phase transformation temperature range. Thus, there is less or no need for external compensation (for example, variable capacitors or waveform modification) to adjust for changes in the inductive load of the temperature limited heater to maintain a relatively high power factor.

[0676] In certain embodiments, the temperature limited heater, which confines the majority of the flow of electrical current to the electrical conductor below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor, maintains the power factor above 0.85, above 0.9, or above 0.95 during use of the heater. Any reduction in the power

factor occurs only in sections of the temperature limited heater at temperatures near the Curie temperature and/or the phase transformation temperature range. Most sections of the temperature limited heater are typically not at or near the Curie temperature and/or the phase transformation temperature range during use. These sections have a high power factor that approaches 1.0. The power factor for the entire temperature limited heater is maintained above 0.85, above 0.9, or above 0.95 during use of the heater even if some sections of the heater have power factors below 0.85.

[0677] Maintaining high power factors allows for less expensive power supplies and/or control devices such as solid state power supplies or SCRs (silicon controlled rectifiers). These devices may fail to operate properly if the power factor varies by too large an amount because of inductive loads. With the power factors maintained at high values; however, these devices may be used to provide power to the temperature limited heater. Solid state power supplies have the advantage of allowing fine tuning and controlled adjustment of the power supplied to the temperature limited heater.

[0678] In some embodiments, transformers are used to provide power to the temperature limited heater. Multiple voltage taps may be made into the transformer to provide power to the temperature limited heater. Multiple voltage taps allow the current supplied to switch back and forth between the multiple voltages. This maintains the current within a range bound by the multiple voltage taps.

[0679] The highly electrically conductive member, or inner conductor, increases the turndown ratio of the temperature limited heater. In certain embodiments, thickness of the highly electrically conductive member is increased to increase the turndown ratio of the temperature limited heater. In some embodiments, the thickness of the electrical conductor is reduced to increase the turndown ratio of the temperature limited heater. In certain embodiments, the turndown ratio of the temperature limited heater is between 1.1 and 10, between 2 and 8, or between 3 and 6 (for example, the turndown ratio is at least 1.1, at least 2, or at least 3).

[0680] FIG. 26 depicts an embodiment of a temperature limited heater in which the support member provides a majority of the heat output below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. Core 374 is an inner conductor of the temperature limited heater. In certain embodiments, core 374 is a highly electrically conductive material such as copper or aluminum. In some embodiments, core 374 is a copper alloy that provides mechanical strength and good electrically conductivity such as a dispersion strengthened copper. In one embodiment, core 374 is Glidcop® (SCM Metal Products, Inc., Research Triangle Park, North Carolina, U.S.A.). Ferromagnetic conductor 376 is a thin layer of ferromagnetic material between electrical conductor 408 and core 374. In certain

embodiments, electrical conductor 408 is also support member 378. In certain embodiments, ferromagnetic conductor 376 is iron or an iron alloy. In some embodiments, ferromagnetic conductor 376 includes ferromagnetic material with a high relative magnetic permeability. For example, ferromagnetic conductor 376 may be purified iron such as Armco ingot iron (AK Steel Ltd., United Kingdom). Iron with some impurities typically has a relative magnetic permeability on the order of 400. Purifying the iron by annealing the iron in hydrogen gas (H_2) at 1450 °C increases the relative magnetic permeability of the iron. Increasing the relative magnetic permeability of ferromagnetic conductor 376 allows the thickness of the ferromagnetic conductor to be reduced. For example, the thickness of unpurified iron may be approximately 4.5 mm while the thickness of the purified iron is approximately 0.76 mm.

[0681] In certain embodiments, electrical conductor 408 provides support for ferromagnetic conductor 376 and the temperature limited heater. Electrical conductor 408 may be made of a material that provides good mechanical strength at temperatures near or above the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376. In certain embodiments, electrical conductor 408 is a corrosion resistant member. Electrical conductor 408 (support member 378) may provide support for ferromagnetic conductor 376 and corrosion resistance. Electrical conductor 408 is made from a material that provides desired electrically resistive heat output at temperatures up to and/or above the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376.

[0682] In an embodiment, electrical conductor 408 is 347H stainless steel. In some embodiments, electrical conductor 408 is another electrically conductive, good mechanical strength, corrosion resistant material. For example, electrical conductor 408 may be 304H, 316H, 347HH, NF709, Incoloy® 800H alloy (Inco Alloys International, Huntington, West Virginia, U.S.A.), Haynes® HR120® alloy, or Inconel® 617 alloy.

[0683] In some embodiments, electrical conductor 408 (support member 378) includes different alloys in different portions of the temperature limited heater. For example, a lower portion of electrical conductor 408 (support member 378) is 347H stainless steel and an upper portion of the electrical conductor (support member) is NF709. In certain embodiments, different alloys are used in different portions of the electrical conductor (support member) to increase the mechanical strength of the electrical conductor (support member) while maintaining desired heating properties for the temperature limited heater.

[0684] In some embodiments, ferromagnetic conductor 376 includes different ferromagnetic conductors in different portions of the temperature limited heater. Different ferromagnetic conductors may be used in different portions of the temperature limited heater to vary the Curie temperature and/or the phase transformation temperature range and, thus, the maximum

operating temperature in the different portions. In some embodiments, the Curie temperature and/or the phase transformation temperature range in an upper portion of the temperature limited heater is lower than the Curie temperature and/or the phase transformation temperature range in a lower portion of the heater. The lower Curie temperature and/or the phase transformation temperature range in the upper portion increases the creep-rupture strength lifetime in the upper portion of the heater.

[0685] In the embodiment depicted in FIG. 26, ferromagnetic conductor 376, electrical conductor 408, and core 374 are dimensioned so that the skin depth of the ferromagnetic conductor limits the penetration depth of the majority of the flow of electrical current to the support member when the temperature is below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. Thus, electrical conductor 408 provides a majority of the electrically resistive heat output of the temperature limited heater at temperatures up to a temperature at or near the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376. In certain embodiments, the temperature limited heater depicted in FIG. 26 is smaller (for example, an outside diameter of 3 cm, 2.9 cm, 2.5 cm, or less) than other temperature limited heaters that do not use electrical conductor 408 to provide the majority of electrically resistive heat output. The temperature limited heater depicted in FIG. 26 may be smaller because ferromagnetic conductor 376 is thin as compared to the size of the ferromagnetic conductor needed for a temperature limited heater in which the majority of the resistive heat output is provided by the ferromagnetic conductor.

[0686] In some embodiments, the support member and the corrosion resistant member are different members in the temperature limited heater. FIGS. 27 and 28 depict embodiments of temperature limited heaters in which the jacket provides a majority of the heat output below the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. In these embodiments, electrical conductor 408 is jacket 370. Electrical conductor 408, ferromagnetic conductor 376, support member 378, and core 374 (in FIG. 27) or inner conductor 362 (in FIG. 28) are dimensioned so that the skin depth of the ferromagnetic conductor limits the penetration depth of the majority of the flow of electrical current to the thickness of the jacket. In certain embodiments, electrical conductor 408 is a material that is corrosion resistant and provides electrically resistive heat output below the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376. For example, electrical conductor 408 is 825 stainless steel or 347H stainless steel. In some embodiments, electrical conductor 408 has a small thickness (for example, on the order of 0.5 mm).

[0687] In FIG. 27, core 374 is highly electrically conductive material such as copper or aluminum. Support member 378 is 347H stainless steel or another material with good

mechanical strength at or near the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376.

[0688] In FIG. 28, support member 378 is the core of the temperature limited heater and is 347H stainless steel or another material with good mechanical strength at or near the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376. Inner conductor 362 is highly electrically conductive material such as copper or aluminum.

[0689] In some embodiments, a relatively thin conductive layer is used to provide the majority of the electrically resistive heat output of the temperature limited heater at temperatures up to a temperature at or near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. Such a temperature limited heater may be used as the heating member in an insulated conductor heater. The heating member of the insulated conductor heater may be located inside a sheath with an insulation layer between the sheath and the heating member.

[0690] FIGS. 29A and 29B depict cross-sectional representations of an embodiment of the insulated conductor heater with the temperature limited heater as the heating member. Insulated conductor 410 includes core 374, ferromagnetic conductor 376, inner conductor 362, electrical insulator 364, and jacket 370. Core 374 is a copper core. Ferromagnetic conductor 376 is, for example, iron or an iron alloy.

[0691] Inner conductor 362 is a relatively thin conductive layer of non-ferromagnetic material with a higher electrical conductivity than ferromagnetic conductor 376. In certain embodiments, inner conductor 362 is copper. Inner conductor 362 may be a copper alloy. Copper alloys typically have a flatter resistance versus temperature profile than pure copper. A flatter resistance versus temperature profile may provide less variation in the heat output as a function of temperature up to the Curie temperature and/or the phase transformation temperature range. In some embodiments, inner conductor 362 is copper with 6% by weight nickel (for example, CuNi6 or LOHM™). In some embodiments, inner conductor 362 is CuNi10Fe1Mn alloy. Below the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376, the magnetic properties of the ferromagnetic conductor confine the majority of the flow of electrical current to inner conductor 362. Thus, inner conductor 362 provides the majority of the resistive heat output of insulated conductor 410 below the Curie temperature and/or the phase transformation temperature range.

[0692] In certain embodiments, inner conductor 362 is dimensioned, along with core 374 and ferromagnetic conductor 376, so that the inner conductor provides a desired amount of heat output and a desired turndown ratio. For example, inner conductor 362 may have a cross-sectional area that is around 2 or 3 times less than the cross-sectional area of core 374. Typically,

inner conductor 362 has to have a relatively small cross-sectional area to provide a desired heat output if the inner conductor is copper or copper alloy. In an embodiment with copper inner conductor 362, core 374 has a diameter of 0.66 cm, ferromagnetic conductor 376 has an outside diameter of 0.91 cm, inner conductor 362 has an outside diameter of 1.03 cm, electrical insulator 364 has an outside diameter of 1.53 cm, and jacket 370 has an outside diameter of 1.79 cm. In an embodiment with a CuNi6 inner conductor 362, core 374 has a diameter of 0.66 cm, ferromagnetic conductor 376 has an outside diameter of 0.91 cm, inner conductor 362 has an outside diameter of 1.12 cm, electrical insulator 364 has an outside diameter of 1.63 cm, and jacket 370 has an outside diameter of 1.88 cm. Such insulated conductors are typically smaller and cheaper to manufacture than insulated conductors that do not use the thin inner conductor to provide the majority of heat output below the Curie temperature and/or the phase transformation temperature range.

[0693] Electrical insulator 364 may be magnesium oxide, aluminum oxide, silicon dioxide, beryllium oxide, boron nitride, silicon nitride, or combinations thereof. In certain embodiments, electrical insulator 364 is a compacted powder of magnesium oxide. In some embodiments, electrical insulator 364 includes beads of silicon nitride.

[0694] In certain embodiments, a small layer of material is placed between electrical insulator 364 and inner conductor 362 to inhibit copper from migrating into the electrical insulator at higher temperatures. For example, a small layer of nickel (for example, about 0.5 mm of nickel) may be placed between electrical insulator 364 and inner conductor 362.

[0695] Jacket 370 is made of a corrosion resistant material such as, but not limited to, 347 stainless steel, 347H stainless steel, 446 stainless steel, or 825 stainless steel. In some embodiments, jacket 370 provides some mechanical strength for insulated conductor 410 at or above the Curie temperature and/or the phase transformation temperature range of ferromagnetic conductor 376. In certain embodiments, jacket 370 is not used to conduct electrical current.

[0696] In certain embodiments, a semiconductor layer is placed outside of the core of an insulated conductor heater. The semiconductor layer may at least partially surround the core. The semiconductor layer may be located adjacent to the core (between the core and the insulation layer (electrical insulator)) or the semiconductor layer may be located in the insulation layer. Placing the semiconductor layer in the insulated conductor heater outside the core may mitigate electric field fluctuations in the heater and/or reduce the electric field strength in the heater. Thus, a higher voltage may be applied to an insulated conductor heater with the semiconductor layer that yields the same maximum electric field strength between the core and the sheath as achieved with a lower voltage applied to an insulated conductor heater without the semiconductor layer. Alternatively, a lower maximum field strength results for the insulated

conductor heater with the semiconducting layer when the two heaters are energized to the same voltage.

[0697] FIG. 30 depicts an embodiment of insulated conductor 410 with semiconductor layer 1370 adjacent to and surrounding core 374 (on the surface of the core). Insulated conductor 410 may be an insulated conductor heater that provides resistive heat output. Electrical insulator 364 and jacket (sheath) 370 surround semiconductor layer 1370 and core 374. FIG. 31 depicts an embodiment of insulated conductor 410 with semiconductor layer 1370 inside electrical insulator 364 and surrounding core 374. Semiconductor layer 1370 may be, for example, $BaTiO_3$ or another suitable semiconducting material such as, but not limited to, $Ba_xSr_{1-x}TiO_3$, $CaCu_3(TiO_3)_4$, or $La_2Ba_2CaZn_2Ti_3O_4$. In certain embodiments, core 374 is copper or a copper alloy (for example a copper-nickel alloy), electrical insulator 364 is magnesium oxide, and jacket 370 is stainless steel.

[0698] Semiconductor layer 1370 reduces the electric field strength outside of core 374. In addition, having semiconductor layer 1370 surrounding core 374 may reduce or mitigate electric field fluctuations due to defects or irregularities in the surface of the core. Reducing the electric field strength and/or mitigating electric field fluctuations may reduce stresses on electrical insulator 364, reducing potential breakdown of the electrical insulator and increasing the operational lifetime of the heater.

[0699] In certain embodiments, semiconductor layer 1370 has a higher dielectric constant than electrical insulator 364. In certain embodiments, the electric field strength around the core is minimized by optimizing the dielectric constant of the semiconductor layer and the thickness of the semiconductor layer. The dielectric constant of semiconductor layer 1370 and/or electrical insulator 364 may be graded (vary with radial distance from the central axis of core 374) to optimize the effect on the electric field. In some embodiments, multiple layers, each with a different dielectric constant (either semiconductor layers or electrical insulator layers), are used to provide a desired grading.

[0700] For long vertical temperature limited heaters (for example, heaters at least 300 m, at least 500 m, or at least 1 km in length), the hanging stress becomes important in the selection of materials for the temperature limited heater. Without the proper selection of material, the support member may not have sufficient mechanical strength (for example, creep-rupture strength) to support the weight of the temperature limited heater at the operating temperatures of the heater.

[0701] In certain embodiments, materials for the support member are varied to increase the maximum allowable hanging stress at operating temperatures of the temperature limited heater and, thus, increase the maximum operating temperature of the temperature limited heater. Altering the materials of the support member affects the heat output of the temperature limited

heater below the Curie temperature and/or the phase transformation temperature range because changing the materials changes the resistance versus temperature profile of the support member. In certain embodiments, the support member is made of more than one material along the length of the heater so that the temperature limited heater maintains desired operating properties (for example, resistance versus temperature profile below the Curie temperature and/or the phase transformation temperature range) as much as possible while providing sufficient mechanical properties to support the heater. In some embodiments, transition sections are used between sections of the heater to provide strength that compensates for the difference in temperature between sections of the heater. In certain embodiments, one or more portions of the temperature limited heater have varying outside diameters and/or materials to provide desired properties for the heater.

[0702] For relatively long insulated conductor heaters (for example, heaters at least 300 m, at least 500 m, or at least 1 km in length), the voltage decreases to much smaller values (for example, less than 500 V) at or near the ends of the heaters distal from the surface, where the voltage is much higher (for example, 3 kV or higher). Because the voltages decreases to smaller values along the length of the heater, the thickness of the insulation may also decrease along the length of the heater as less insulation is needed to inhibit electrical breakdown at lower voltages. Using less insulation may allow the portions of the insulated conductor heater further from the surface to be thinner and result in lower material costs.

[0703] In certain embodiments, the electrical insulator in an insulated conductor heater tapers from a larger thickness at or near the surface to a smaller thickness at or near the end of the heater distal from the surface. In some embodiments, the electrical insulator in an insulated conductor heater tapers from a larger thickness at or near the junction of the overburden section of the heater and the section of the heater in a hydrocarbon containing layer to a smaller thickness at or near the end of the heater distal from the surface. In some embodiments, the thickness of the electrical insulator continuously tapers from the larger thickness to the smaller thickness along a length of the insulated conductor heater.

[0704] In certain embodiments, the thickness of the insulated conductor heater tapers from a larger thickness to a smaller thickness because of the tapered thickness of the electrical insulator. The dimensions of electrical conductors (for example, the core and the jacket) may remain substantially constant along the length of the heater such that the tapered electrical insulator provides for the tapered thickness of the heater. FIG. 32 depicts an embodiment of a tapered portion of insulated conductor 410. Core 374 and jacket 370 have substantially constant thicknesses while the thickness of electrical insulator 364 tapers. The tapered thickness of

electrical insulator 364 tapers the thickness of insulated conductor 410. Tapering only the electrical insulator may save on manufacturing costs and/or material costs.

[0705] The electrical insulator may be tapered, for example, by using rollers to gradually shrink the size of the electrical insulator during an assembly process used to make the insulated conductor heater. Another possible method for tapering the insulation is to use electrical insulator blocks of gradually decreasing thickness along the length of the heater. Yet another possible method is to telescope or taper the thickness of individual electrical insulator blocks along the length of the heater.

[0706] The tapered insulated conductor heater with a thinner end portion at or near the distal end of the heater allows a smaller electrical termination to be used at the end of the heater. A smaller termination allows the opening at the end of the heater to be smaller, which is easier and/or less costly to form (drill). FIG. 33 depicts an embodiment of tapered insulated conductor 410 in opening 386. Insulated conductor 410 tapers to smaller dimensions at or near the end of opening 386 distal from the surface of the formation. The smaller end portion of opening 386 allows termination 420 to be smaller than if there was no tapering of the size of insulated conductor 410 and opening 386. In some embodiments, if the voltage reduces to a sufficiently low value at the end of the heater, it may be possible to have no termination at the end of the heater or allow the heater to ground to the formation.

[0707] In some embodiments, the thinner end portion of the tapered insulated conductor heater allows the end portion of the heater to be looped into a hairpin configuration. FIG. 34 depicts an embodiment of tapered insulated conductor 410 in a hairpin configuration. Thus, the heater can return current to the surface and be terminated at the surface instead of being terminated in the subsurface. In some embodiments, current is returned to the surface through the jacket or sheath of the insulated conductor heater. The core of the tapered insulated conductor heater is shorted to the jacket (sheath) at the end of the heater distal from the surface so that current runs down the core and returns on the sheath. FIG. 35 depicts an embodiment of tapered insulated conductor 410 with core 374 coupled (shorted) to jacket 370 with termination 420. Using the hairpin configuration and/or shorting the core and the jacket allows the insulated conductor heater to be used as a single-phase heater with electrical connections only at the surface.

[0708] In certain embodiments of temperature limited heaters, three temperature limited heaters are coupled together in a three-phase wye configuration. Coupling three temperature limited heaters together in the three-phase wye configuration lowers the current in each of the individual temperature limited heaters because the current is split between the three individual heaters. Lowering the current in each individual temperature limited heater allows each heater to have a small diameter. The lower currents allow for higher relative magnetic permeabilities in each of

the individual temperature limited heaters and, thus, higher turndown ratios. In addition, there may be no return current path needed for each of the individual temperature limited heaters. Thus, the turndown ratio remains higher for each of the individual temperature limited heaters than if each temperature limited heater had its own return current path.

[0709] In the three-phase wye configuration, individual temperature limited heaters may be coupled together by shorting the sheaths, jackets, or canisters of each of the individual temperature limited heaters to the electrically conductive sections (the conductors providing heat) at their terminating ends (for example, the ends of the heaters at the bottom of a heater wellbore). In some embodiments, the sheaths, jackets, canisters, and/or electrically conductive sections are coupled to a support member that supports the temperature limited heaters in the wellbore.

[0710] In certain embodiments, coupling multiple heaters (for example, mineral insulated conductor heaters) to a single power source, such as a transformer, is advantageous. Coupling multiple heaters to a single transformer may result in using fewer transformers to power heaters used for a treatment area as compared to using individual transformers for each heater. Using fewer transformers reduces surface congestion and allows easier access to the heaters and surface components. Using fewer transformers reduces capital costs associated with providing power to the treatment area. In some embodiments, at least 4, at least 5, at least 10, at least 25 heaters, at least 35 heaters, or at least 45 heaters are powered by a single transformer. Additionally, powering multiple heaters (in different heater wells) from the single transformer may reduce overburden losses because of reduced voltage and/or phase differences between each of the heater wells powered by the single transformer. Powering multiple heaters from the single transformer may inhibit current imbalances between the heaters because the heaters are coupled to the single transformer.

[0711] To provide power to multiple heaters using the single transformer, the transformer may have to provide power at higher voltages to carry the current to each of the heaters effectively. In certain embodiments, the heaters are floating (ungrounded) heaters in the formation. Floating the heaters allows the heaters to operate at higher voltages. In some embodiments, the transformer provides power output of at least about 3 kV, at least about 4 kV, at least about 5 kV, or at least about 6 kV.

[0712] FIG. 36 depicts a top view representation of heater 412 with three insulated conductors 410 in conduit 406. Heater 412 may be located in a heater well in the subsurface formation. Conduit 406 may be a sheath, jacket, or other enclosure around insulated conductors 410. Each insulated conductor 410 includes core 374, electrical insulator 364, and jacket 370. Insulated conductors 410 may be mineral insulated conductors with core 374 being a copper alloy (for example, a copper-nickel alloy such as Alloy 180), electrical insulator 364 being magnesium

oxide, and jacket 370 being Incoloy® 825, copper, or stainless steel (for example 347H stainless steel). In some embodiments, jacket 370 includes non-work hardenable metals so that the jacket is annealable.

[0713] In some embodiments, core 374 and/or jacket 370 include ferromagnetic materials. In some embodiments, one or more insulated conductors 410 are temperature limited heaters. In certain embodiments, the overburden portion of insulated conductors 410 include high electrical conductivity materials in core 374 (for example, pure copper or copper alloys such as copper with 3% silicon at a weld joint) so that the overburden portions of the insulated conductors provide little or no heat output. In certain embodiments, conduit 406 includes non-corrosive materials and/or high strength materials such as stainless steel. In one embodiment, conduit 406 is 347H stainless steel.

[0714] Insulated conductors 410 may be coupled to the single transformer in a three-phase configuration (for example, a three-phase wye configuration). Each insulated conductor 410 may be coupled to one phase of the single transformer. In certain embodiments, the single transformer is also coupled to a plurality of identical heaters 412 in other heater wells in the formation (for example, the single transformer may couple to 40 or more heaters in the formation). In some embodiments, the single transformer couples to at least 4, at least 5, at least 10, at least 15, or at least 25 additional heaters in the formation.

[0715] Electrical insulator 364' may be located inside conduit 406 to electrically insulate insulated conductors 410 from the conduit. In certain embodiments, electrical insulator 364' is magnesium oxide (for example, compacted magnesium oxide). In some embodiments, electrical insulator 364' is silicon nitride (for example, silicon nitride blocks). Electrical insulator 364' electrically insulates insulated conductors 410 from conduit 406 so that at high operating voltages (for example, 3 kV or higher), there is no arcing between the conductors and the conduit. In some embodiments, electrical insulator 364' inside conduit 406 has at least the thickness of electrical insulators 364 in insulated conductors 410. The increased thickness of insulation in heater 412 (from electrical insulators 364 and/or electrical insulator 364') inhibits and may prevent current leakage into the formation from the heater. In some embodiments, electrical insulator 364' spatially locates insulated conductors 410 inside conduit 406.

[0716] FIG. 37 depicts an embodiment of three-phase wye transformer 414 coupled to a plurality of heaters 412. For simplicity in the drawing, only four heaters 412 are shown in FIG. 37. It is to be understood that several more heaters may be coupled to the transformer 414. As shown in FIG. 37, each leg (each insulated conductor) of each heater is coupled to one phase of transformer 414 and current is returned to the neutral or ground of the transformer (for example, returned through conductor 416 depicted in FIGS. 36 and 38).

[0717] Return conductor 416 may be electrically coupled to the ends of insulated conductors 410 (as shown in FIG. 38) current returns from the ends of the insulated conductors to the transformer on the surface of the formation. Return conductor 416 may include high electrical conductivity materials such as pure copper, nickel, copper alloys, or combinations thereof so that the return conductor provides little or no heat output. In some embodiments, return conductor 416 is a tubular (for example, a stainless steel tubular) that allows an optical fiber to be placed inside the tubular to be used for temperature and/or other measurement. In some embodiments, return conductor 416 is a small insulated conductor (for example, small mineral insulated conductor). Return conductor 416 may be coupled to the neutral or ground leg of the transformer in a three-phase wye configuration. Thus, insulated conductors 410 are electrically isolated from conduit 406 and the formation. Using return conductor 416 to return current to the surface may make coupling the heater to a wellhead easier. In some embodiments, current is returned using one or more of jackets 370, depicted in FIG. 36. One or more jackets 370 may be coupled to cores 374 at the end of the heaters and return current to the neutral of the three-phase wye transformer.

[0718] FIG. 38 depicts a side view representation of the end section of three insulated conductors 410 in conduit 406. The end section is the section of the heaters the furthest away from (distal from) the surface of the formation. The end section includes contactor section 418 coupled to conduit 406. In some embodiments, contactor section 418 is welded or brazed to conduit 406. Termination 420 is located in contactor section 418. Termination 420 is electrically coupled to insulated conductors 410 and return conductor 416. Termination 420 electrically couples the cores of insulated conductors 410 to the return conductor 416 at the ends of the heaters.

[0719] In certain embodiments, heater 412, depicted in FIGS. 36 and 38, includes an overburden section using copper as the core of the insulated conductors. The copper in the overburden section may be the same diameter as the cores used in the heating section of the heater. The copper in the overburden section may have a larger diameter than the cores in the heating section of the heater. Increasing the size of the copper in the overburden section may decrease losses in the overburden section of the heater.

[0720] Heaters that include three insulated conductors 410 in conduit 406, as depicted in FIGS. 36 and 38, may be made in a multiple step process. In some embodiments, the multiple step process is performed at the site of the formation or treatment area. In some embodiments, the multiple step process is performed at a remote manufacturing site away from the formation. The finished heater is then transported to the treatment area.

[0721] Insulated conductors 410 may be pre-assembled prior to the bundling either on site or at a remote location. Insulated conductors 410 and return conductor 416 may be positioned on spools. A machine may draw insulated conductors 410 and return conductor 416 from the spools

at a selected rate. Preformed blocks of insulation material may be positioned around return conductor 416 and insulated conductors 410. In an embodiment, two blocks are positioned around return conductor 416 and three blocks are positioned around insulated conductors 410 to form electrical insulator 364'. The insulated conductors and return conductor may be drawn or pushed into a plate of conduit material that has been rolled into a tubular shape. The edges of the plate may be pressed together and welded (for example, by laser welding). After forming conduit 406 around electrical insulator 364', the bundle of insulated conductors 410, and return conductor 416, the conduit may be compacted against the electrical insulator 416 so that all of the components of the heater are pressed together into a compact and tightly fitting form. During the compaction, the electrical insulator may flow and fill any gaps inside the heater.

[0722] In some embodiments, heater 412 (which includes conduit 406 around electrical insulator 364' and the bundle of insulated conductors 410 and return conductor 416) is inserted into a coiled tubing tubular that is placed in a wellbore in the formation. The coiled tubing tubular may be left in place in the formation (left in during heating of the formation) or removed from the formation after installation of the heater. The coiled tubing tubular may allow for easier installation of heater 412 into the wellbore.

[0723] In some embodiments, one or more components of heater 412 are varied (for example, removed, moved, or replaced) while the operation of the heater remains substantially identical. FIG. 39 depicts an embodiment of heater 412 with three insulated cores 374 in conduit 406. In this embodiment, electrical insulator 364' surrounds cores 374 and return conductor 416 in conduit 406. Cores 374 are located in conduit 406 without an electrical insulator and jacket surrounding the cores. Cores 374 are coupled to the single transformer in a three-phase wye configuration with each core 374 coupled to one phase of the transformer. Return conductor 416 is electrically coupled to the ends of cores 374 and returns current from the ends of the cores to the transformer on the surface of the formation.

[0724] FIG. 40 depicts an embodiment of heater 412 with three insulated conductors 410 and insulated return conductor in conduit 406. In this embodiment, return conductor 416 is an insulated conductor with core 374, electrical insulator 364, and jacket 370. Return conductor 416 and insulated conductors 410 are located in conduit 406 surrounded by electrical insulator 364'. Return conductor 416 and insulated conductors 410 may be the same size or different sizes. Return conductor 416 and insulated conductors 410 operate substantially the same as in the embodiment depicted in FIGS. 36 and 38.

[0725] Mineral insulated (MI) cables (insulated conductors) for use in subsurface applications, such as heating hydrocarbon containing formations in some applications, are longer, may have larger outside diameters, and may operate at higher voltages and temperatures than what is

typical in the MI cable industry. For these subsurface applications, the joining of multiple MI cables is needed to make MI cables with sufficient length to reach the depths and distances needed to heat the subsurface efficiently and to join segments with different functions, such as lead-in cables joined to heater sections. Such long heaters also require higher voltages to provide enough power to the farthest ends of the heaters.

[0726] Conventional MI cable splice designs are typically not suitable for voltages above 1000 volts, above 1500 volts, or above 2000 volts and may not operate for extended periods without failure at elevated temperatures, such as over 650 °C (about 1200 °F), over 700 °C (about 1290 °F), or over 800 °C (about 1470 °F). Such high voltage, high temperature applications typically require the compaction of the mineral insulant in the splice to be as close as possible to or above the level of compaction in the insulated conductor (MI cable) itself.

[0727] The relatively large outside diameter and long length of MI cables for some applications requires that the cables be spliced while oriented horizontally. There are splices for other applications of MI cables that have been fabricated horizontally. These techniques typically use a small hole through which the mineral insulation (such as magnesium oxide powder) is filled into the splice and compacted slightly through vibration and tamping. Such methods do not provide sufficient compaction of the mineral insulation or even allow any compaction of the mineral insulation, and are not suitable for making splices for use at the high voltages needed for these subsurface applications.

[0728] Thus, there is a need for splices of insulated conductors that are simple yet can operate at the high voltages and temperatures in the subsurface environment over long durations without failure. In addition, the splices may need higher bending and tensile strengths to inhibit failure of the splice under the weight loads and temperatures that the cables can be subjected to in the subsurface. Techniques and methods also may be utilized to reduce electric field intensities in the splices so that leakage currents in the splices are reduced and to increase the margin between the operating voltage and electrical breakdown. Reducing electric field intensities may help increase voltage and temperature operating ranges of the splices.

[0729] FIG. 41 depicts a side view cross-sectional representation of one embodiment of a fitting for joining insulated conductors. Fitting 422 is a splice or coupling joint for joining insulated conductors 410A, 410B. In certain embodiments, fitting 422 includes sleeve 424 and housings 426A, 426B. Housings 426A, 426B may be splice housings, coupling joint housings, coupler housings. Sleeve 424 and housings 426A, 426B may be made of mechanically strong, electrically conductive materials such as, but not limited to, stainless steel. Sleeve 424 and housings 426A, 426B may be cylindrically shaped or polygon shaped. Sleeve 424 and housings

426A, 426B may have rounded edges, tapered diameter changes, other features, or combinations thereof, which may reduce electric field intensities in fitting 422.

[0730] Fitting 422 may be used to couple (splice) insulated conductor 410A to insulated conductor 410B while maintaining the mechanical and electrical integrity of the jackets (sheaths), insulation, and cores (conductors) of the insulated conductors. Fitting 422 may be used to couple heat producing insulated conductors with non-heat producing insulated conductors, to couple heat producing insulated conductors with other heat producing insulated conductors, or to couple non-heat producing insulated conductors with other non-heat producing insulated conductors. In some embodiments, more than one fitting 422 is used in to couple multiple heat producing and non-heat producing insulated conductors to produce a long insulated conductor.

[0731] Fitting 422 may be used to couple insulated conductors with different diameters, as shown in FIG. 41. For example, the insulated conductors may have different core (conductor) diameters, different jacket (sheath) diameters, or combinations of different diameters. Fitting 422 may also be used to couple insulated conductors with different metallurgies, different types of insulation, or a combination thereof.

[0732] As shown in FIG. 41, housing 426A is coupled to jacket (sheath) 370A of insulated conductor 410A and housing 426B is coupled to jacket 370B of insulated conductor 410B. In certain embodiments, housings 426A, 426B are welded, brazed, or otherwise permanently affixed to insulated conductors 410A, 410B. In some embodiments, housings 426A, 426B are temporarily or semi-permanently affixed to jackets 370A, 370B of insulated conductors 410A, 410B (for example, coupled using threads or adhesives). Fitting 422 may be centered between the end portions of the insulated conductors 410A, 410B.

[0733] In certain embodiments, the interior volumes of sleeve 424 and housings 426A, 426B are substantially filled with electrically insulating material 430. In certain embodiments, "substantially filled" refers to entirely or almost entirely filling the volume or volumes with electrically insulating material with substantially no macroscopic voids in the volume or volumes. For example, substantially filled may refer to filling almost the entire volume with electrically insulating material that has some porosity because of microscopic voids (for example, up to about 40% porosity). Electrically insulating material 430 may be magnesium oxide, talc, other electrical insulators such as ceramic powders (for example, boron nitride), a mixture of magnesium oxide and another electrical insulator (for example, up to about 50% by volume boron nitride), ceramic cement, mixtures of ceramic powders with certain non-ceramic materials (such as tungsten sulfide (WS_2)), or mixtures thereof. For example, magnesium oxide may be mixed with boron nitride or another electrical insulator to improve the ability of the electrically

insulating material to flow, to improve the dielectric characteristics of the electrically insulating material, or to improve the flexibility of the fitting. In some embodiments, electrically insulating material 430 is material similar to electrical insulation used inside of at least one of insulated conductors 410A, 410B. Electrically insulating material 430 may have substantially similar dielectric characteristics to electrical insulation used inside of at least one of insulated conductors 410A, 410B.

[0734] In certain embodiments, first sleeve 424 and housings 426A, 426B are made up (for example, put together or manufactured) buried or submerged in electrically insulating material 430. Making up sleeve 424 and housings 426A, 426B buried in electrically insulating material 430 inhibits open space from forming in the interior volumes of the portions. Sleeve 424 and housings 426A, 426B have open ends to allow insulated conductors 410A, 410B to pass through. These open ends may be sized to have diameters slightly larger than the outside diameter of the jackets of the insulated conductors.

[0735] In certain embodiments, cores 374A, 374B of insulated conductors 410A, 410B are joined together at coupling 428. The jackets and insulation of insulated conductors 410A, 410B may be cut back or stripped to expose desired lengths of cores 374A, 374B before joining the cores. Coupling 428 may be located in electrically insulating material 430 inside sleeve 424.

[0736] Coupling 428 may join cores 374A, 374B together, for example, by compression, crimping, brazing, welding, or other techniques known in the art. In some embodiments, core 374A is made of different material than core 374B. For example, core 374A may be copper while core 374B is stainless steel, carbon steel, or Alloy 180. In such embodiments, special methods may have to be used to weld the cores together. For example, the tensile strength properties and/or yield strength properties of the cores may have to be matched closely such that the coupling between the cores does not degrade over time or with use.

[0737] In some embodiments, a copper core may be work-hardened before joining the core to carbon steel or Alloy 180. In some embodiments, the cores are coupled by in-line welding using filler material (for example, filler metal) between the cores of different materials. For example, Monel® (Special Metals Corporation, New Hartford, NY, U.S.A.) nickel alloys may be used as filler material. In some embodiments, copper cores are buttered (melted and mixed) with the filler material before the welding process.

[0738] In an embodiment, insulated conductors 410A, 410B are coupled using fitting 422 by first sliding housing 426A over jacket 370A of insulated conductor 410A and, second, sliding housing 426B over jacket 370B of insulated conductor 410B. The housings are slid over the jackets with the large diameter ends of the housings facing the ends of the insulated conductors. Sleeve 424 may be slid over insulated conductor 410B such that it is adjacent to housing 426B. Cores 374A,

374B are joined at coupling 428 to create a robust electrical and mechanical connection between the cores. The small diameter end of housing 426A is joined (for example, welded) to jacket 370A of insulated conductor 410A. Sleeve 424 and housing 426B are brought (moved or pushed) together with housing 426A to form fitting 422. The interior volume of fitting 422 may be substantially filled with electrically insulating material while the sleeve and the housings are brought together. The interior volume of the combined sleeve and housings is reduced such that the electrically insulating material substantially filling the entire interior volume is compacted. Sleeve 424 is joined to housing 426B and housing 426B is joined to jacket 370B of insulated conductor 410B. The volume of sleeve 424 may be further reduced, if additional compaction is desired.

[0739] In certain embodiments, the interior volumes of housings 426A, 426B filled with electrically insulating material 430 have tapered shapes. The diameter of the interior volumes of housings 426A, 426B may taper from a smaller diameter at or near the ends of the housings coupled to insulated conductors 410A, 410B to a larger diameter at or near the ends of the housings located inside sleeve 424 (the ends of the housings facing each other or the ends of the housings facing the ends of the insulated conductors). The tapered shapes of the interior volumes may reduce electric field intensities in fitting 422. Reducing electric field intensities in fitting 422 may reduce leakage currents in the fitting at increased operating voltages and temperatures, and may increase the margin to electrical breakdown. Thus, reducing electric field intensities in fitting 422 may increase the range of operating voltages and temperatures for the fitting.

[0740] In some embodiments, the insulation from insulated conductors 410A, 410B tapers from jackets 370A, 370B down to cores 374A, 374B in the direction toward the center of fitting 422 in the event that the electrically insulating material 430 is a weaker dielectric than the insulation in the insulated conductors. In some embodiments, the insulation from insulated conductors 410A, 410B tapers from jackets 370A, 370B down to cores 374A, 374B in the direction toward the insulated conductors in the event that electrically insulating material 430 is a stronger dielectric than the insulation in the insulated conductors. Tapering the insulation from the insulated conductors reduces the intensity of electric fields at the interfaces between the insulation in the insulated conductors and the electrically insulating material within the fitting.

[0741] FIG. 42 depicts a tool that may be used to cut away part of the inside of insulated conductors 410A, 410B (for example, electrical insulation inside the jacket of the insulated conductor). Cutting tool 436 may include cutting teeth 438 and drive tube 440. Drive tube 440 may be coupled to the body of cutting tool 436 using, for example, a weld or braze. In some embodiments, no cutting tool is needed to cut away electrical insulation from inside the jacket.

[0742] Sleeve 424 and housings 426A, 426B may be coupled together using any means known in the art such as brazing, welding, or crimping. In some embodiments, in the embodiment shown in FIG. 43, sleeve 424 and housings 426A, 426B have threads that engage to couple the pieces together.

[0743] As shown in FIGS. 41 and 43, in certain embodiments, electrically insulating material 430 is compacted during the assembly process. The force to press the housings 426A, 426B toward each other may put a pressure on electrically insulating material 430 of at least 25,000 pounds per square inch, or between 25,000 and 55,000 pounds per square inch, in order to provide acceptable compaction of the insulating material. The tapered shapes of the interior volumes of housings 426A, 426B and the make-up of electrically insulating material 430 may enhance compaction of the electrically insulating material during the assembly process to the point where the dielectric characteristics of the electrically insulating material are, to the extent practical, comparable to that within insulated conductors 410A, 410B. Methods and devices to facilitate compaction include, but are not limited to, mechanical methods (such as shown in FIG. 46), pneumatic, hydraulic (such as shown in FIGS. 47 and 48), swaged, or combinations thereof.

[0744] The combination of moving the pieces together with force and the housings having the tapered interior volumes compacts electrically insulating material 430 using both axial and radial compression. Using both axial and radial compression of electrically insulating material 430 provides more uniform compaction of the electrically insulating material. In some embodiments, vibration and/or tamping of electrically insulating material 430 may also be used to consolidate the electrically insulating material. Vibration (and/or tamping) may be applied either at the same time as application of force to push the housings 426A, 426B together, or vibration (and/or tamping) may be alternated with application of such force. Vibration and/or tamping may reduce bridging of particles in electrically insulating material 430.

[0745] In the embodiment depicted in FIG. 43, electrically insulating material 430 inside housings 426A, 426B is compressed mechanically by tightening nuts 434 against ferrules 432 coupled to jackets 370A, 370B. The mechanical method compacts the interior volumes of housings 426A, 426B because of the tapered shape of the interior volumes. Ferrules 432 may be copper or other soft metal ferrules. Nuts 434 may be stainless steel or other hard metal nut that is movable on jackets 370A, 370B. Nuts 434 may engage threads on housings 426A, 426B to couple to the housings. As nuts 434 are threaded onto housings 426A, 426B, nuts 434 and ferrules 432 work to compress the interior volumes of the housings. In some embodiments, nuts 434 and ferrules 432 may work to move housings 426A, 426B further onto sleeve 424 (using the threaded coupling between the pieces) and compact the interior volume of the sleeve. In some embodiments, housings 426A, 426B and sleeve 424 are coupled together using the threaded

coupling before the nut and ferrule are swaged down on the second portion. As the interior volumes inside housings 426A, 426B are compressed, the interior volume inside sleeve 424 may also be compressed. In some embodiments, nuts 434 and ferrules 432 may act to couple housings 426A, 426B to insulated conductors 410A, 410B.

[0746] In certain embodiments, multiple insulated conductors are spliced together in an end fitting. For example, three insulated conductors may be spliced together in an end fitting to couple electrically the insulated conductors in a 3-phase wye configuration. FIG. 44A depicts a side view of a cross-sectional representation of an embodiment of threaded fitting 442 for coupling three insulated conductors 410A, 410B, 410C. FIG. 44B depicts a side view of a cross-sectional representation of an embodiment of welded fitting 442 for coupling three insulated conductors 410A, 410B, 410C. As shown in FIGS. 44A and 44B, insulated conductors 410A, 410B, 410C may be coupled to fitting 442 through end cap 444. End cap 444 may include three strain relief fittings 446 through which insulated conductors 410A, 410B, 410C pass.

[0747] Cores 374A, 374B, 374C of the insulated conductors may be coupled together at coupling 428. Coupling 428 may be, for example, a braze (such as a silver braze or copper braze), a welded joint, or a crimped joint. Coupling cores 374A, 374B, 374C at coupling 428 electrically join the three insulated conductors for use in a 3-phase wye configuration.

[0748] As shown in FIG. 44A, end cap 444 may be coupled to main body 448 of fitting 442 using threads. Threading of end cap 444 and main body 448 may allow the end cap to compact electrically insulating material 430 inside the main body. At the end of main body 448 opposite of end cap 444 is cover 450. Cover 450 may also be attached to main body 448 by threads. In certain embodiments, compaction of electrically insulating material 430 in fitting 442 is enhanced through tightening of cover 450 into main body 448, by crimping of the main body after attachment of the cover, or a combination of these methods.

[0749] As shown in FIG. 44B, end cap 444 may be coupled to main body 448 of fitting 442 using welding, brazing, or crimping. End cap 444 may be pushed or pressed into main body 448 to compact electrically insulating material 430 inside the main body. Cover 450 may also be attached to main body 448 by welding, brazing, or crimping. Cover 450 may be pushed or pressed into main body 448 to compact electrically insulating material 430 inside the main body. Crimping of the main body after attachment of the cover may further enhance compaction of electrically insulating material 430 in fitting 442.

[0750] In some embodiments, as shown in FIGS. 44A and 44B, plugs 452 close openings or holes in cover 450. For example, the plugs may be threaded, welded, or brazed into openings in cover 450. The openings in cover 450 may allow electrically insulating material 430 to be provided inside fitting 442 when cover 450 and end cap 444 are coupled to main body 448. The

openings in cover 450 may be plugged or covered after electrically insulating material 430 is provided inside fitting 442. In some embodiments, openings are located on main body 448 of fitting 442. Openings on main body 448 may be plugged with plugs 452 or other plugs.

[0751] In some embodiments, cover 450 includes one or more pins. In some embodiments, the pins are or are part of plugs 452. The pins may engage a torque tool that turns cover 450 and tightens the cover on main body 448. An example of torque tool 454 that may engage the pins is depicted in FIG. 45. Torque tool 454 may have an inside diameter that substantially matches the outside diameter of cover 450 (depicted in FIG. 44A). As shown in FIG. 45, torque tool 454 may have slots or other depressions that are shaped to engage the pins on cover 450. Torque tool 454 may include recess 456. Recess 456 may be a square drive recess or other shaped recess that allows operation (turning) of the torque tool.

[0752] FIG. 46 depicts an embodiment of clamp assemblies 458A,B that may be used to mechanically compact fitting 422. Clamp assemblies 458A,B may be shaped to secure fitting 422 in place at the shoulders of housings 426A, 426B. Threaded rods 462 may pass through holes 460 of clamp assemblies 458A,B. Nuts 468, along with washers, on each of threaded rods 462 may be used to apply force on the outside faces of each clamp assembly and bring the clamp assemblies together such that compressive forces are applied to housings 426A, 426B of fitting 422. These compressive forces compact electrically insulating material inside fitting 422.

[0753] In some embodiments, clamp assemblies 458 are used in hydraulic, pneumatic, or other compaction methods. FIG. 47 depicts an exploded view of an embodiment of hydraulic compaction machine 464. FIG. 48 depicts a representation of an embodiment of assembled hydraulic compaction machine 464. As shown in FIGS. 47 and 48, clamp assemblies 458 may be used to secure fitting 422 (depicted, for example, in FIG. 41) in place with insulated conductors coupled to the fitting. At least one clamp assembly (for example, clamp assembly 458A) may be moveable together to compact the fitting in the axial direction. Power unit 466, shown in FIG. 47, may be used to power compaction machine 464.

[0754] FIG. 49 depicts an embodiment of fitting 422 and insulated conductors 410A, 410B secured in clamp assembly 458A and clamp assembly 458B before compaction of the fitting and insulated conductors. As shown in FIG. 49, the cores of insulated conductors 410A, 410B are coupled using coupling 428 at or near the center of sleeve 424. Sleeve 424 is slid over housing 426A, which is coupled to insulated conductor 410A. Sleeve 424 and housing 426A are secured in fixed (non-moving) clamp assembly 458B. Insulated conductor 410B passes through housing 426B and movable clamp assembly 458A. Insulated conductor 410B may be secured by another clamp assembly fixed relative to clamp assembly 458B (not shown). Clamp assembly 458A may be moved towards clamp assembly 458B to couple housing 426B to sleeve 424 and compact

electrically insulating material inside the housings and the sleeve. Interfaces between insulated conductor 410A and housing 426A, between housing 426A and sleeve 424, between sleeve 424 and housing 426B, and between housing 426B and insulated conductor 410B may then be coupled by welding, brazing, or other techniques known in the art.

[0755] FIG. 50 depicts a side view representation of an embodiment of fitting 470 for joining insulated conductors. Fitting 470 may be a cylinder or sleeve that has sufficient clearance between the inside diameter of the sleeve and the outside diameters of insulated conductors 410A, 410B such that the sleeve fits over the ends of the insulated conductors. The cores of insulated conductors 410A, 410B may be joined inside fitting 470. The jackets and insulation of insulated conductors 410A, 410B may be cut back or stripped to expose desired lengths of the cores before joining the cores. Fitting 470 may be centered between the end portions of insulated conductors 410A, 410B.

[0756] Fitting 470 may be used to couple insulated conductor 410A to insulated conductor 410B while maintaining the mechanical and electrical integrity of the jackets, insulation, and cores of the insulated conductors. Fitting 470 may be used to couple heat producing insulated conductors with non-heat producing insulated conductors, to couple heat producing insulated conductors with other heat producing insulated conductors, or to couple non-heat producing insulated conductors with other non-heat producing insulated conductors. In some embodiments, more than one fitting 470 is used in to couple multiple heat producing and non-heat producing insulated conductors to produce a long insulated conductor.

[0757] Fitting 470 may be used to couple insulated conductors with different diameters. For example, the insulated conductors may have different core diameters, different jacket diameters, or combinations of different diameters. Fitting 470 may also be used to couple insulated conductors with different metallurgies, different types of insulation, or a combination thereof.

[0758] In certain embodiments, fitting 470 has at least one angled end. For example, the ends of fitting 470 may be angled relative to the longitudinal axis of the fitting. The angle may be, for example, about 45° or between 30° and 60°. Thus, the ends of fitting 470 may have substantially elliptical cross-sections. The substantially elliptical cross-sections of the ends of fitting 470 provide a larger area for welding or brazing of the fitting to insulated conductors 410A, 410B. The larger coupling area increases the strength of spliced insulated conductors. In the embodiment shown in FIG. 50, the angled ends of fitting 470 give the fitting a substantially parallelogram shape.

[0759] The angled ends of fitting 470 provide higher tensile strength and higher bending strength for the fitting than if the fitting had straight ends by distributing loads along the fitting. Fitting 470 may be oriented so that when insulated conductors 410A, 410B and the fitting are spooled

(for example, on a coiled tubing installation), the angled ends act as a transition in stiffness from the fitting body to the insulated conductors. This transition reduces the likelihood of the insulated conductors to kink or crimp at the end of the fitting body.

[0760] As shown in FIG. 50, fitting 470 includes opening 472. Opening 472 allows electrically insulating material (such as electrically insulating material 430, depicted in FIG. 41) to be provided (filled) inside fitting 470. Opening 472 may be a slot or other longitudinal opening extending along part of the length of fitting 470. In certain embodiments, opening 472 extends substantially the entire gap between the ends of insulated conductors 410A, 410B inside fitting 470. Opening 472 allows substantially the entire volume (area) between insulated conductors 410A, 410B, and around any welded or spliced joints between the insulated conductors, to be filled with electrically insulating material without the insulating material having to be moved axially toward the ends of the volume between the insulated conductors. The width of opening 472 allows electrically insulating material to be forced into the opening and packed more tightly inside fitting 470, thus, reducing the amount of void space inside the fitting. Electrically insulating material may be forced through the slot into the volume between insulated conductors 410A, 410B, for example, with a tool with the dimensions of the slot. The tool may be forced into the slot to compact the insulating material. Then, additional insulating material may be added and the compaction is repeated. In some embodiments, the electrically insulating material may be further compacted inside fitting 470 using vibration, tamping, or other techniques. Further compacting the electrically insulating material may more uniformly distribute the electrically insulating material inside fitting 470.

[0761] After filling electrically insulating material inside fitting 470 and, in some embodiment, compaction of the electrically insulating material, opening 472 may be closed. For example, an insert or other covering may be placed over the opening and secured in place. FIG. 51 depicts a side view representation of an embodiment of fitting 470 with opening 472 covered with insert 474. Insert 474 may be welded or brazed to fitting 470 to close opening 472. In some embodiments, insert 474 is ground or polished so that the insert if flush on the surface of fitting 470. Also depicted in FIG. 51, welds or brazes 476 may be used to secure fitting 470 to insulated conductors 410A, 410B.

[0762] After opening 472 is closed, fitting 470 may be compacted mechanically, hydraulically, pneumatically, or using swaging methods to compact further the electrically insulating material inside the fitting. Further compaction of the electrically insulating material reduces void volume inside fitting 470 and reduces the leakage currents through the fitting and increases the operating range of the fitting (for example, the maximum operating voltages or temperatures of the fitting).

[0763] In certain embodiments, fitting 470 includes certain features that may further reduce electric field intensities inside the fitting. For example, fitting 470 or coupling 428 of the cores of the insulated conductors inside the fitting may include tapered edges, rounded edges, or other smoothed out features to reduce electric field intensities. FIG. 52 depicts an embodiment of fitting 470 with electric field reducing features at coupling 428 between insulated conductors 410A, 410B. As shown in FIG. 52, coupling 428 is a welded joint with a smoothed out or rounded profile to reduce electric field intensity inside fitting 470. In addition, fitting 470 has a tapered interior volume to increase the volume of electrically insulating material inside the fitting. Having the tapered and larger volume may reduce electric field intensities inside fitting 470.

[0764] In some embodiments, electric field stress reducers may be located inside fitting 470 to decrease the electric field intensity. FIG. 53 depicts an embodiment of electric field stress reducer 478. Reducer 478 may be located in the interior volume of fitting 470 (shown in FIG. 52). Reducer 478 may be a split ring or other separable piece so that the reducer can be fitted around cores 374A, 374B of insulated conductors 410A, 410B after they are joined (shown in FIG. 52).

[0765] The fittings depicted herein (such as fitting 422, depicted in FIGS. 41 and 43, fitting 442, depicted in FIG. 44, and fitting 470, depicted in FIGS. 50, 51, and 52) may form robust electrical and mechanical connections between insulated conductors. For example, fittings depicted herein may be suitable for extended operation at voltages above 1000 volts, above 1500 volts, or above 2000 volts and temperatures of at least about 650 °C, at least about 700 °C, at least about 800 °C.

[0766] In certain embodiments, the fittings depicted herein couple insulated conductors used for heating (for example, insulated conductors located in a hydrocarbon containing layer) to insulated conductors not used for heating (for example, insulated conductors used in overburden sections of the formation). The heating insulated conductor may have a smaller core and different material core than the non-heating insulated conductor. For example, the core of the heating insulated conductor may be a copper-nickel alloy, stainless steel, or carbon steel while the core of the non-heating insulated conductor may be copper. Because of the difference in sizes and electrical properties of materials of the cores, however, the electrical insulation in the sections may have sufficiently different thicknesses that cannot be compensated in a single fitting joining the insulated conductors. Thus, in some embodiments, a short section of intermediate heating insulated conductor may be used in between the heating insulated conductor and the non-heating insulated conductor.

[0767] The intermediate heating insulated conductor may have a core diameter that tapers from the core diameter of the non-heating insulated conductor to the core diameter of the heating

insulated conductor while using core material similar to the non-heating insulated conductor. For example, the intermediate heating insulated conductor may be copper with a core diameter that tapers to the same diameter as the heating insulated conductor. Thus, the thickness of the electrical insulation at the fitting coupling the intermediate insulated conductor and the heating insulated conductor is similar to the thickness of the electrical insulation in the heating insulated conductor. Having the same thickness allows the insulated conductors to be easily joined in the fitting. The intermediate heating insulated conductor may provide some voltage drop and some heating losses because of the smaller core diameter, however, the intermediate heating insulated conductor may be relatively short in length such that these losses are minimal.

[0768] FIGS. 54 and 55 depict cross-sectional representations of another embodiment of fitting 422 used for joining insulated conductors. FIG. 54 depicts a cross-sectional representation of fitting 422 as insulated conductors 410A, 410B are being moved into the fitting. FIG. 55 depicts a cross-sectional representation of fitting 422 with insulated conductors 410A, 410B joined inside the fitting. In certain embodiments, fitting 422 includes sleeve 424 and coupling 428.

[0769] Coupling 428 is used to join and electrically couple cores 374A, 374B of insulated conductors 410A, 410B inside fitting 422. Coupling 428 may be made of copper or another suitable electrical conductor. In certain embodiments, cores 374A, 374B are press fit or pushed into coupling 428. In some embodiments, coupling 428 is heated to enable cores 374A, 374B to be slid into the coupling. In some embodiments, coupling 428 includes one or more grooves on the inside of the coupling. The grooves may inhibit particles from entering or exiting the coupling after the cores are joined in the coupling. In some embodiments, coupling 428 has a tapered inner diameter (for example, tighter inside diameter towards the center of the coupling). The tapered inner diameter may provide a better press fit between coupling 428 and cores 374A, 374B.

[0770] In certain embodiments, electrically insulating material 430 is located inside sleeve 424. Electrically insulating material 430 may be magnesium oxide, boron nitride, other electrically insulating materials, or combinations thereof. For example, in some embodiments, electrically insulating material 430 is magnesium oxide or a mixture of magnesium oxide and boron nitride (80% magnesium oxide and 20% boron nitride by volume). In some embodiments, sleeve 424 has one or more grooves 1346. Grooves 1346 may inhibit electrically insulating material 430 from moving out of sleeve 424 (for example, the grooves trap the electrically insulating material in the sleeve).

[0771] In certain embodiments, electrically insulating material 430 has concave shaped end portions at or near the edges of coupling 428, as shown in FIG. 54. The concave shapes of electrically insulating material 430 may enhance coupling with electrical insulators 364A, 364B

of insulated conductors 410A, 410B. In some embodiments, electrical insulators 364A, 364B have convex shaped (or tapered) end portions to enhance coupling with electrically insulating material 430. The end portions of electrically insulating material 430 and electrical insulators 364A, 364B may comingle or mix under the pressure applied during joining of the insulated conductors. The comingling or mixing of the insulation materials may enhance the coupling between the insulated conductors.

[0772] In certain embodiments, insulated conductors 410A, 410B are joined with fitting 422 by moving (pushing) the insulated conductors together towards the center of the fitting. Cores 374A, 374B are brought together inside coupling 428 with the movement of insulated conductors 410A, 410B. After insulated conductors 410A, 410B are moved together into fitting 422, the fitting and end portions of the insulated conductors inside the fitting may be compacted or pressed to secure the insulated conductors in the fitting and compress electrically insulating material 430. Clamp assemblies (such as those depicted in FIG. 49) or other similar devices may be used to bring together insulated conductors 410A, 410B and fitting 422. In some embodiments, end portions of sleeve 424 are coupled (welded or brazed) to jackets 370A, 370B of insulated conductors 410A, 410B. In some embodiments, a support sleeve and/or strain reliefs are placed over fitting 422 to provide additional strength to the fitting.

[0773] There are many potential problems in making insulated conductors in relatively long lengths (for example, lengths of 10 m or longer). For example, gaps may exist between blocks of material used to form the electrical insulator in the insulated conductor. These gaps may lead to bulges or mechanical defects in the core or other components of the insulated conductor. Insulated conductors include insulated conductor used as heaters and/or insulated conductors used in the overburden section of the formation (insulated conductors that provide little or no heat output). Insulated conductors may be, for example, mineral insulated conductors such as mineral insulated cables.

[0774] In a typical process used to make (form) an insulated conductor, the jacket of the insulated conductor starts as a strip of electrically conducting material (for example, stainless steel). The jacket strip is formed (longitudinally rolled) into a partial cylindrical shape and electrical insulator blocks (for example, magnesium oxide blocks) are inserted into the partially cylindrical jacket. The inserted blocks may be partial cylinder blocks such as half-cylinder blocks. Following insertion of the blocks, the longitudinal core, which is typically a solid cylinder, is placed in the partial cylinder and inside the half-cylinder blocks. The core is made of electrically conducting material such as copper, nickel, and/or steel.

[0775] Once the electrical insulator blocks and the core are in place, the portion of the jacket containing the blocks and the core may be formed into a complete cylinder around the blocks and

the core. The longitudinal edges of the jacket that close the cylinder may be welded to form an insulated conductor assembly with the core and electrical insulator blocks inside the jacket. The process of inserting the blocks and closing the jacket cylinder may be repeated along a length of jacket to form the insulated conductor assembly in a desired length.

[0776] As the insulated conductor assembly is formed, further steps may be taken to reduce gaps in the assembly. For example, the insulated conductor assembly may be moved through a progressive reduction system to reduce gaps in the assembly. One example of a progressive reduction system is a roller system. In the roller system, the insulated conductor assembly may progress through multiple horizontal and vertical rollers with the assembly alternating between horizontal and vertical rollers. The rollers may progressively reduce the size of the insulated conductor assembly into the final, desired outside diameter.

[0777] If the electrical insulator blocks are allowed to freely sit in the jacket during the insulated conductor assembly reduction process, one or more of the blocks may have gaps between them that allow problems such as core bulge or other mechanical defects to occur in the reduced insulated conductor assembly. Such occurrences may lead to electrical problems during use of the insulated conductor assembly and may potentially render the assembly inoperable for its intended purpose. Thus, a reliable method is needed to ensure that gaps between the electrical insulator blocks are reduced or eliminated during the insulated conductor assembly reduction process.

[0778] In certain embodiments, an axial force is placed on the blocks inside the insulated conductor assembly to minimize gaps between the blocks. For example, as one or more blocks are inserted in the insulated conductor assembly, the inserted blocks may be pushed (either mechanically or pneumatically) axially along the assembly against blocks already in the assembly. Pushing the inserted blocks against the blocks already in the insulated conductor assembly with a sufficient force minimizes gaps between blocks by providing and maintaining a force between blocks along the length of the assembly as the assembly is moved through the assembly reduction process.

[0779] FIGS. 56-58 depict one embodiment of block pushing device 1348 that may be used to provide axial force to blocks in the insulated conductor assembly. In certain embodiments, as shown in FIG. 56, device 1348 includes insulated conductor holder 1350, plunger guide 1352, and air cylinders 1354. Device 1348 may be located in an assembly line used to make insulated conductor assemblies. In certain embodiments, device 1348 is located at the part of the assembly line used to insert blocks into the jacket. For example, device 1348 is located between the steps of longitudinally rolling the jacket strip into a partial cylindrical shape and insertion of the core into the insulated conductor assembly. After insertion of the core, the jacket containing the

blocks and the core may be formed into a complete cylinder. In some embodiments, the core is inserted before the blocks and the blocks are inserted around the core and inside the jacket.

[0780] In certain embodiments, insulated conductor holder 1350 is shaped to hold part of the jacket 370 and allow the jacket assembly to move through the insulated conductor holder while other parts of the jacket simultaneously move through other portions of the assembly line. Insulated conductor holder 1350 may be coupled to plunger guide 1352 and air cylinders 1354.

[0781] In certain embodiments, block holder 1356 is coupled to insulated conductor holder 1350. Block holder 1356 may be a device used to store and insert blocks 1358 into jacket 370. In certain embodiments, blocks 1358 are formed from two half-cylinder blocks 1358A, 1358B. Blocks 1358 may be made from an electrical insulator suitable for use in the insulated conductor assembly such as, but not limited to, magnesium oxide. In some embodiments, blocks 1358 are about 6" in length. The length of blocks 1358 may, however, vary as desired or needed for the insulated conductor assembly.

[0782] A divider may be used to separate blocks 1358A, 1358B in block holder 1356 so that the blocks may be properly inserted into jacket 370. As shown in FIG. 58, blocks 1358A, 1358B may be gravity fed from block holder 1356 into jacket 370 as the jacket passes through insulated conductor holder 1350. Blocks 1358A, 1358B may be inserted in a direct side-by-side arrangement into jacket 370 (after insertion, the blocks rest directly side-by-side horizontally in the jacket).

[0783] As blocks 1358A, 1358B are inserted into jacket 370, the blocks may be moved (pushed) towards previously inserted blocks to remove gaps between the blocks inside the jacket. Blocks 1358A, 1358B may be moved towards previously inserted blocks using plunger 1360, shown in FIG. 58. Plunger 1360 may be located inside jacket 370 such that the plunger provides pressure to the blocks inside the jacket and not to the jacket itself.

[0784] In certain embodiments, plunger 1360 has a cross-sectional shape that allows the plunger to move freely inside jacket 370 and provide axial force on the blocks without providing force on the core inside the jacket. FIG. 59 depicts an embodiment of plunger 1360 with a cross-sectional shape that allows the plunger to provide force on the blocks but not on the core inside the jacket. In some embodiments, plunger 1360 is made of ceramic or is coated with a ceramic material. An example of a ceramic material that may be used is zirconia toughened alumina (ZTA). Using a ceramic or ceramic coated plunger may inhibit abrasion of the blocks by the plunger when force is applied to the blocks by the plunger.

[0785] In certain embodiments, air cylinders 1354 are coupled to plunger guide 1352 with one or more rods (shown in FIGS. 56 and 57). Air cylinders 1354 and plunger guide 1352 may be inline with jacket 370 and plunger 1360 to inhibit adding angular moment to the blocks or the jacket.

Air cylinders 1354 may be operated using bi-directional valves so that the air cylinders can be extended or retracted based on which side of the air cylinders is provided with positive air pressure. When air cylinders 1354 are extended (as shown in FIG. 56), plunger guide 1352 moves away from insulated conductor holder 1350 so that plunger 1360 is cleared out of the way and allows blocks 1358A, 1358B to be inserted (for example, dropped) into jacket 370 from block holder 1356.

[0786] When air cylinders 1354 retract (as shown in FIG. 57), plunger guide 1352 moves towards to plunger 1360 and plunger 1360 provides a selected amount of force on blocks 1358A, 1358B. Plunger 1360 provides the selected amount of force on blocks 1358A, 1358B to push the blocks onto blocks previously inserted into jacket 370. The amount of force provided by plunger 1360 on blocks 1358A, 1358B may be selected to based on the factors such as, but not limited to, the speed of the jacket as it moves through the assembly line, the amount of force needed to inhibit gaps forming between adjacent blocks in the jacket, the maximum amount of force that may be applied to the blocks without damaging the blocks, or combinations thereof. For example, the selected amount of force may be between about 100 pounds of force and about 500 pounds of force (for example, about 400 pounds of force). In certain embodiments, the selected amount of force is the minimum amount of force needed to inhibit the gaps from existing between adjacent blocks in the jacket. The selected amount of force may be determined by the amount of air pressure provided to the air cylinders.

[0787] After blocks 1358A, 1358B are pushed against previously inserted blocks, air pressure in air cylinders 1354 is reversed and the air cylinders extend such that plunger 1360 is retracted and additional blocks are drop into jacket 370 from block holder 1356. This process may be repeated until jacket 370 is filled with blocks up to a desired length for the insulated conductor assembly.

[0788] In certain embodiments, plunger 1360 is moved back and forth (extended and retracted) using a cam that alternates the direction of air pressure provided to air cylinders 1354. The cam may, for example, be coupled to a bi-directional valve used to operate the air cylinders. The cam may have a first position that operates the valve to extend the air cylinders and a second position that operates the valve to retract the air cylinders. The cam may be moved between the first and second positions by operation of the plunger such that the cam switches the operation of air cylinders between extension and retraction.

[0789] Providing the intermittent force on blocks 1358A, 1358B from the extension and retraction of plunger 1360 provides the selected amount of force on the string of blocks inserted into jacket 370. Providing this force to the string of blocks in the jacket removes and inhibits gaps from forming between adjacent blocks. Inhibiting gaps between blocks reduces the potential for mechanical and/or electrical failure in the insulated conductor assembly.

[0790] In some embodiments, blocks 1358A, 1358B are inserted into jacket 370 in other methods besides the direct side-by-side arrangement described above. For example, the blocks may be inserted in a staggered side-by-side arrangement where the blocks are offset along the length of the jacket. In such an arrangement, the plunger may have a different shape to accommodate the offset blocks. For example, FIG. 60 depicts an embodiment of plunger 1360 that may be used to push offset (staggered) blocks. As another example, the blocks may be inserted in a top/bottom arrangement (one half-cylinder block on top of another half-cylinder block). The top/bottom arrangement may have the blocks either directly on top of each other or in an offset (staggered) relationship. FIG. 61 depicts an embodiment of plunger 1360 that may be used to push top/bottom arranged blocks. Offsetting or staggering the block inside the jacket may inhibit rotation of the blocks relative to blocks before or after the inserted blocks.

[0791] Another source of potential problems in insulated conductors with relatively long lengths (for example, lengths of 10 m or longer) is that the electrical properties of the electrical insulator may degrade over time. Any small change in an electrical property (for example, resistivity) may lead to failure of the insulated conductor. Since the electrical insulator used in the long length insulated conductor is typically made of several blocks of electrical insulator, as described above, improvements in the processes used to make the blocks of electrical insulator may increase the reliability of the insulated conductor. In certain embodiments, the electrical insulator is improved to have a resistivity that remains substantially constant over time during use of the insulated conductor (for example, during production of heat by an insulated conductor heater).

[0792] In some embodiments, electrical insulator blocks (such as magnesium oxide blocks) are purified to remove impurities that may cause degradation of the blocks over time. For example, raw material used for the electrical insulator blocks may be heated to higher temperatures to convert metal oxide impurities to elemental metal (for example, iron oxide impurities may be converted to elemental iron). Elemental metal may be removed from the raw electrical insulator material more easily than metal oxide. Thus, purity of the raw electrical insulator material may be improved by heating the raw material to higher temperatures before removal of the impurities. The raw material may be heated to higher temperatures by, for example, using a plasma discharge.

[0793] In some embodiments, the electrical insulator blocks are made using hot pressing, a method known in the art for making ceramics. Hot pressing of the electrical insulator blocks may get the raw material in the blocks to fuse at points of contact in the insulated conductor heater. Fusing of the blocks at points of contact may improve the electrical properties of the electrical insulator.

[0794] In some embodiments, the electrical insulator blocks are cooled in an oven using dried or purified air. Using dried or purified air may decrease the addition of impurities or moisture to the blocks during the cooling process. Removing moisture from the blocks may increase the reliability of electrical properties of the blocks.

[0795] In some embodiments, the electrical insulator blocks are not heat treated during the process of making the blocks. Not heat treating the blocks may maintain the resistivity in the blocks and inhibit degradation of the blocks over time. In some embodiments, the electrical insulator blocks are heated at slow heating rates to help maintain resistivity in the blocks.

[0796] In some embodiments, the core of the insulated conductor is coated with a material that inhibits migration of impurities into the electrical insulator of the insulated conductor. For example, coating of an Alloy 180 core with nickel or Inconel® 625 might inhibit migration of materials from the Alloy 180 into the electrical insulator. In some embodiments, the core is made of material that does not migrate into the electrical insulator. For example, a carbon steel core may not cause degradation of the electrical insulator over time.

[0797] In some embodiments, the electrical insulator is made from powdered raw material such as powdered magnesium oxide. Powdered magnesium oxide may resist degradation better than other types of magnesium oxide.

[0798] In some embodiments, three insulated conductor heaters (for example, mineral insulated conductor heaters) are coupled together into a single assembly. The single assembly may be built in long lengths and may operate at high voltages (for example, voltages of 4000 V nominal). In certain embodiments, the individual insulated conductor heaters are enclosed in corrosive resistant jackets to resist damage from the external environment. The jackets may be, for example, seam welded stainless steel armor similar to that used on type MC/CWCMC cable.

[0799] In some embodiments, three insulated conductor heaters are cabled and the insulating filler added in conventional methods known in the art. The insulated conductor heaters may include one or more heater sections that resistively heat and provide heat to formation adjacent to the heater sections. The insulated conductors may include one or more other sections that provide electricity to the heater sections with relatively small heat loss. The individual insulated conductor heaters may be wrapped with high temperature fiber tapes before being placed on a take-up reel (for example, a coiled tubing rig). The reel assembly may be moved to another machine for application of an outer metallic sheath or outer protective conduit.

[0800] In some embodiments, the fillers include glass, ceramic or other temperature resistant fibers that withstand operating temperature of 760 °C or higher. In addition, the insulated conductor cables may be wrapped in multiple layers of a ceramic fiber woven tape material. By wrapping the tape around the cabled insulated conductor heaters prior to application of the outer

metallic sheath, electrical isolation is provided between the insulated conductor heaters and the outer sheath. This electrical isolation inhibits leakage current from the insulated conductor heaters passing into the subsurface formation and forces any leakage currents to return directly to the power source on the individual insulated conductor sheaths and/or on a lead-in conductor or lead-out conductor coupled to the insulated conductors. The lead-in or lead-out conductors may be coupled to the insulated conductors when the insulated conductors are placed into an assembly with the outer metallic sheath.

[0801] In certain embodiments, the insulated conductor heaters are wrapped with a metallic tape or other type of tape instead of the high temperature ceramic fiber woven tape material. The metallic tape holds the insulated conductor heaters together. A widely-spaced wide pitch spiral wrapping of a high temperature fiber rope may be wrapped around the insulated conductor heaters. The fiber rope may provide electrical isolation between the insulated conductors and the outer sheath. The fiber rope may be added at any stage during assembly. For example, the fiber rope may be added as a part of the final assembly when the outer sheath is added. Application of the fiber rope may be simpler than other electrical isolation methods because application of the fiber rope is done with only a single layer of rope instead of multiple layers of ceramic tape. The fiber rope may be less expensive than multiple layers of ceramic tape. The fiber rope may increase heat transfer between the insulated conductors and the outer sheath and/or reduce interference with any welding process used to weld the outer sheath around the insulated conductors (for example, seam welding).

[0802] In certain embodiments, an insulated conductor or another type of heater is installed in a wellbore or opening in the formation using outer tubing coupled to a coiled tubing rig. FIG. 62 depicts outer tubing 480 partially unspooled from coiled tubing rig 482. Outer tubing 480 may be made of metal or polymeric material. Outer tubing 480 may be a flexible conduit such as, for example, a tubing guide string or other coiled tubing string. Heater 412 may be pushed into outer tubing 480, as shown in FIG. 63. In certain embodiments, heater 412 is pushed into outer tubing 480 by pumping the heater into the outer tubing.

[0803] In certain embodiments, one or more flexible cups 484 are coupled to the outside of heater 412. Flexible cups 484 may have a variety of shapes and/or sizes but typically are shaped and sized to maintain at least some pressure inside at least a portion of outer tubing 480 as heater 412 is pushed or pumped into the outer tubing. Flexible cups 484 are made of flexible materials such as, but not limited to, elastomeric materials. For example, flexible cups 484 may have flexible edges that provide limited mechanical resistance as heater 412 is pushed into outer tubing 480 but remain in contact with the inner walls of outer tubing 480 as the heater is pushed so that pressure is maintained between the heater and the outer tubing. Maintaining at least some

pressure in outer tubing 480 between flexible cups 484 allows heater 412 to be continuously pushed into the outer tubing with lower pump pressures. Without flexible cups 484, higher pressures may be needed to push heater 412 into outer tubing 480. In some embodiments, cups 484 allow some pressure to be released while maintaining pressure in outer tubing 480. In certain embodiments, flexible cups 484 are spaced to distribute pumping forces optimally along heater 412 inside outer tubing 480. For example, flexible cups 484 may be evenly spaced along heater 412.

[0804] Heater 412 is pushed into outer tubing 480 until the heater is fully inserted into the outer tubing, as shown in FIG. 64. Drilling guide 486 may be coupled to the end of heater 412. Heater 412, outer tubing 480, and drilling guide 486 may be spooled onto coiled tubing rig 482, as shown in FIG. 65. After heater 412, outer tubing 480, and drilling guide 486 are spooled onto coiled tubing rig 482, the assembly may be transported to a location for installation of the heater. For example, the assembly may be transported to the location of a subsurface heater wellbore (opening).

[0805] FIG. 66 depicts coiled tubing rig 482 being used to install heater 412 and outer tubing 480 into opening 386 using drilling guide 486. In certain embodiments, opening 386 is an L-shaped opening or wellbore with a substantially horizontal or inclined portion in a hydrocarbon containing layer of the formation. In such embodiments, heater 412 has a heating section that is placed in the substantially horizontally or inclined portion of opening 386 to be used to heat the hydrocarbon containing layer. In some embodiments, opening 386 has a horizontal or inclined section that is at least about 1000 m in length, at least about 1500 m in length, or at least about 2000 m in length. Overburden casing 398 may be located around the outer walls of opening 386 in an overburden section of the formation. In some embodiments, drilling fluid is left in opening 386 after the opening has been completed (the opening has been drilled).

[0806] FIG. 67 depicts heater 412 and outer tubing 480 installed in opening 386. Gap 488 may be left at or near the far end of heater 412 and outer tubing 480. Gap 488 may allow for heater expansion in opening 386 after the heater is energized.

[0807] After heater 412 and outer tubing 480 are installed in opening 386, the outer tubing may be removed from the opening to leave the heater in place in the opening. FIG. 68 depicts outer tubing 480 being removed from opening 386 while leaving heater 412 installed in the opening. Outer tubing 480 is spooled back onto coiled tubing rig 482 as the outer tubing is pulled off heater 412. In some embodiments, outer tubing 480 is pumped down to balance pressure between opening 386 and the outer tubing. Balancing the pressure allows outer tubing 480 to be pulled off heater 412.

[0808] FIG. 69 depicts outer tubing 480 used to provide packing material 402 into opening 386. As outer tubing 480 reaches the "shoe" or bend in opening 386, the outer tubing may be used to provide packing material into the opening. The shoe of opening 386 may be located at or near the bottom of overburden casing 398. Packing material 402 may be provided (for example, pumped) through outer tubing 480 and out the end of the outer tubing at the shoe of opening 386. Packing material 402 is provided into opening 386 to seal off the opening around heater 412. Packing material 402 provides a barrier between the overburden section and the heating section of opening 386. In certain embodiments, packing material 402 is cement or another suitable plugging material. In some embodiments, outer tubing 480 is continuously spooled while packing material 402 is provided into opening 386. Outer tubing 480 may be spooled slowly while packing material 402 is provided into opening 386 to allow the packing material to settle into the opening properly.

[0809] After packing material 402 is provided into opening 386, outer tubing 480 is spooled further onto coiled tubing rig 482, as shown in FIG. 70. FIG. 71 depicts outer tubing 480 spooled onto coiled tubing rig 482 with heater 412 installed in opening 386. In certain embodiments, flexible cups 484 are spaced in the portion of opening 386 with overburden casing 398 to facilitate adequate stand-off of heater 412 in the overburden portion of the opening. Flexible cups 484 may electrically insulate heater 412 from overburden casing 398. For example, flexible cups 484 may space apart heater 412 and overburden casing 398 such that they are not in physical contact with each other.

[0810] After outer tubing 480 is removed from opening 386, wellhead 392 and/or other completions may be installed at the surface of the opening, as shown in FIG. 72. When heater 412 is energized to begin heating, flexible cups 484 may begin to burn or melt off. In some embodiments, flexible cups 484 begin to burn or melt off at low temperatures during early stages of the heating process.

[0811] In certain embodiments, two or more heaters (for example, insulated conductor heaters) are helically wound onto a spool (for example, a coiled tubing rig) and then unwound from the spool as the heaters are installed into an opening in the subsurface formation. Helically winding the heaters on the spool reduces stresses on the heaters, particularly the outside portions of the heater that may otherwise stretch or elongate.

[0812] FIG. 73 depicts an embodiment of heaters 412 being helically wound on spool 1364. In some embodiments, spool 1364 is part of coiled tubing rig 482 (depicted in FIGS. 62-72). Heaters 412 may be pulled through twist head 1366 and onto spool 1364. Twist head 1366 rotates as heaters 412 are pulled through the twist head and fed onto spool 1364. Because of the rotation motion of twist head 1366, heaters 412 are helically wound as they are fed onto spool

1364. To install heaters 412 in the formation, the heaters may be unwound from spool 1364 and installed into the formation. The helical winding process may be carried out using techniques and/or equipment used for making and using helical flowline bundles for subsea applications described in U.S. Pat. No. 4,843,713 to Langner et al., U.S. Pat. No. 4,979,296 to Langner et al., and U.S. Pat. No. 5,390,481 to Langner.

[0813] FIG. 74 depicts an embodiment of three heaters 412 helically wound together. In some embodiments, three heaters 412 are helically wound together around a support. FIG. 75 depicts an embodiment of three heaters 412 helically wound around support 1368. In some embodiments, one or more clamps 1362 (depicted in FIG. 74) are used to secure heaters 412 in the helically wound configuration. Clamps 1362 may be, for example, glass clamps, glass wraps, or other suitable devices for securing heaters 412 and/or securing the heaters to support 1368.

[0814] Heaters 412 may be helically wound with a selected pitch in the helical winding. In certain embodiments, the selected pitch is between about 5% and 10% (for example, about 7%). In some embodiments, the pitch is varied or changed to vary the heat output provided by the bundle of helically wound heaters. Changing the pitch varies the thickness of the bundle of heaters and, thus, varies the heat output from the bundle. In some embodiments, the pitch is varied along the length of the heaters to vary the heat output along the length of the heaters.

[0815] Helically winding heaters 412 and installing the heaters in the helical winding may reduce stresses on parts of the heaters such as the electrical insulator or jacket of insulated conductor heaters. Helically winding heaters 412 may accommodate thermal expansion of the heaters in the wellbore by, for example, reducing stress on or in the heaters during thermal expansion of the heaters. In certain embodiments, heaters 412 are easier to helically wind if the heaters have a tapered thickness (for example, the heaters are insulated conductors with a tapered thickness).

[0816] FIG. 76 depicts an embodiment of a heater in wellbore 490 in formation 492. The heater includes insulated conductor 410 in conduit 382 with material 494 between the insulated conductor and the conduit. In some embodiments, insulated conductor 410 is a mineral insulated conductor. Electricity supplied to insulated conductor 410 resistively heats the insulated conductor. Insulated conductor conductively transfers heat to material 494. Heat may transfer within material 494 by heat conduction and/or by heat convection. Radiant heat from insulated conductor 410 and/or heat from material 494 transfers to conduit 382. Heat may transfer to the formation from the heater by conductive or radiative heat transfer from conduit 382. Material 494 may be molten metal, molten salt, or other liquid. In some embodiments, a gas (for example, nitrogen, carbon dioxide, and/or helium) is in conduit 382 above material 494. The gas may inhibit oxidation or other chemical changes of material 494. The gas may inhibit vaporization of material 494. U.S. Published Patent Application 2008-0078551 to DeVault et al. describes a

system for placement in a wellbore, the system including a heater in a conduit with a liquid metal between the heater and the conduit for heating subterranean earth.

[0817] Insulated conductor 410 and conduit 382 may be placed in an opening in a subsurface formation. Insulated conductor 410 and conduit 382 may have any orientation in a subsurface formation (for example, the insulated conductor and conduit may be substantially vertical or substantially horizontally oriented in the formation). Insulated conductor 410 includes core 374, electrical insulator 364, and jacket 370. In some embodiments, core 374 is a copper core. In some embodiments, core 374 includes other electrical conductors or alloys (for example, copper alloys). In some embodiments, core 374 includes a ferromagnetic conductor so that insulated conductor 410 operates as a temperature limited heater. In some embodiments, core 374 does not include a ferromagnetic conductor.

[0818] In some embodiments, core 374 of insulated conductor 410 is made of two or more portions. The first portion may be placed adjacent to the overburden. The first portion may be sized and/or made of a highly conductive material so that the first portion does not resistively heat to a high temperature. One or more other portions of core 410 may be sized and/or made of material that resistively heats to a high temperature. These portions of core 410 may be positioned adjacent to sections of the formation that are to be heated by the heater. In some embodiments, the insulated conductor does not include a highly conductive first portion. A lead in cable may be coupled to the insulated conductor to supply electricity to the insulated conductor.

[0819] In some embodiments, core 374 of insulated conductor 410 is a highly conductive material such as copper. Core 374 may be electrically coupled to jacket 370 at or near the end of the insulated conductor. In some embodiments, insulated conductor 410 is electrically coupled to conduit 382. Electrical current supplied to insulated conductor 410 may resistively heat core 374, jacket 370, material 494, and/or conduit 382. Resistive heating of core 374, jacket 370, material 494, and/or conduit 382 generates heat that may transfer to the formation.

[0820] Electrical insulator 364 may be magnesium oxide, aluminum oxide, silicon dioxide, beryllium oxide, boron nitride, silicon nitride, or combinations thereof. In certain embodiments, electrical insulator 364 is a compacted powder of magnesium oxide. In some embodiments, electrical insulator 364 includes beads of silicon nitride. In certain embodiments, a thin layer of material is clad over core 374 to inhibit the core from migrating into the electrical insulator at higher temperatures (to inhibit copper of the core from migrating into magnesium oxide of the insulation). For example, a small layer of nickel (for example, about 0.5 mm of nickel) may be clad on core 374.

[0821] In some embodiments, material 494 may be relatively corrosive. Jacket 370 and/or at least the inside surface of conduit 382 may be made of a corrosion resistant material such as, but not limited to, nickel, Alloy N (Carpenter Metals), 347 stainless steel, 347H stainless steel, 446 stainless steel, or 825 stainless steel. For example, conduit 382 may be plated or lined with nickel. In some embodiments, material 494 may be relatively non-corrosive. Jacket 370 and/or at least the inside surface of conduit 382 may be made of a material such as carbon steel.

[0822] In some embodiments, jacket 370 of insulated conductor 410 is not used as the main return of electrical current for the insulated conductor. In embodiments where material 494 is a good electrical conductor such as a molten metal, current returns through the molten metal in the conduit and/or through the conduit 382. In some embodiments, conduit 382 is made of a ferromagnetic material, (for example 410 stainless steel). Conduit 382 may function as a temperature limited heater until the temperature of the conduit approaches, reaches or exceeds the Curie temperature or phase transition temperature of the conduit material.

[0823] In some embodiments, material 494 returns electrical current to the surface from insulated conductor 410 (the material acts as the return or ground conductor for the insulated conductor). Material 494 may provide a current path with low resistance so that a long insulated conductor 410 is useable in conduit 382. The long heater may operate at low voltages for the length of the heater due to the presence of material 494 that is conductive.

[0824] FIG. 77 depicts an embodiment of a portion of insulated conductor 410 in conduit 382 wherein material 494 is a good conductor (for example, a liquid metal) and current flow is indicated by the arrows. Current flows down core 374 and returns through jacket 370, material 494, and conduit 382. Jacket 370 and conduit 382 may be at approximately constant potential. Current flows radially from jacket 370 to conduit 382 through material 494. Material 494 may resistively heat. Heat from material 494 may transfer through conduit 382 into the formation.

[0825] In embodiments where material 494 is partially electrically conductive (for example, the material is a molten salt), current returns mainly through jacket 370. All or a portion of the current that passes through partially conductive material 494 may pass to ground through conduit 382.

[0826] In the embodiment depicted in FIG. 76, core 374 of insulated conductor 410 has a diameter of about 1 cm, electrical insulator 364 has an outside diameter of about 1.6 cm, and jacket 370 has an outside diameter of about 1.8 cm. In other embodiments, the insulated conductor is smaller. For example, core 374 has a diameter of about 0.5 cm, electrical insulator 364 has an outside diameter of about 0.8 cm, and jacket 370 has an outside diameter of about 0.9 cm. Other insulated conductor geometries may be used. For the same size conduit 382, the smaller geometry of insulated conductor 410 may result in a higher operating temperature of the

insulated conductor to achieve the same temperature at the conduit. The smaller geometry insulated conductors may be significantly more economically favorable due to manufacturing cost, weight, and other factors.

[0827] Material 494 may be placed between the outside surface of insulated conductor 410 and the inside surface of conduit 382. In certain embodiments, material 494 is placed in the conduit in a solid form as balls or pellets. Material 494 may melt below the operating temperatures of insulated conductor 410. Material may melt above ambient subsurface formation temperatures. Material 494 may be placed in conduit 382 after insulated conductor 410 is placed in the conduit. In certain embodiments, material 494 is placed in conduit 410 as a liquid. The liquid may be placed in conduit 382 before or after insulated conductor 410 is placed in the conduit (for example, the molten liquid may be poured into the conduit before or after the insulated conductor is placed in the conduit). Additionally, material 494 may be placed in conduit 382 before or after insulated conductor 410 is energized (supplied with electricity). Material 494 may be added to conduit 382 or removed from the conduit after operation of the heater is initialized. Material 494 may be added to or removed from conduit 382 to maintain a desired head of fluid in the conduit. In some embodiments, the amount of material 494 in conduit 382 may be adjusted (added to or depleted) to adjust or balance the stresses on the conduit. Material 494 may inhibit deformation of conduit 382. The head of material 494 in conduit 382 may inhibit the formation from crushing or otherwise deforming the conduit should the formation expand against the conduit. The head of fluid in conduit 382 allows the wall of the conduit to be relatively thin. Having thin conduits 382 may increase the economic viability of using multiple heaters of this type to heat portions of the formation.

[0828] Material 494 may support insulated conductor 410 in conduit 382. The support provided by material 494 of insulated conductor 410 may allow for the deployment of long insulated conductors as compared to insulated conductors positioned only in a gas in a conduit without the use of special metallurgy to accommodate the weight of the insulated conductor. In certain embodiments, insulated conductor 410 is buoyant in material 494 in conduit 382. For example, insulated conductor may be buoyant in molten metal. The buoyancy of insulated conductor 410 reduces creep associated problems in long, substantially vertical heaters. A bottom weight or tie down may be coupled to the bottom of insulated conductor 410 to inhibit the insulated conductor from floating in material 494.

[0829] Material 494 may remain a liquid at operating temperatures of insulated conductor 410. In some embodiments, material 494 melts at temperatures above about 100 °C, above about 200 °C, or above about 300 °C. The insulated conductor may operate at temperatures greater than 200 °C, greater than 400 °C, greater than 600 °C, or greater than 800 °C. In certain

embodiments, material 494 provides enhanced heat transfer from insulated conductor 410 to conduit 382 at or near the operating temperatures of the insulated conductor.

[0830] Material 494 may include metals such as tin, zinc, an alloy such as a 60% by weight tin, 40% by weight zinc alloy; bismuth; indium; cadmium, aluminum; lead; and/or combinations thereof (for example, eutectic alloys of these metals such as binary or ternary alloys). In one embodiment, material 494 is tin. Some liquid metals may be corrosive. The jacket of the insulated conductor and/or at least the inside surface of the canister may need to be made of a material that is resistant to the corrosion of the liquid metal. The jacket of the insulated conductor and/or at least the inside surface of the conduit may be made of materials that inhibit the molten metal from leaching materials from the insulating conductor and/or the conduit to form eutectic compositions or metal alloys. Molten metals may be highly thermal conductive, but may block radiant heat transfer from the insulated conductor and/or have relatively small heat transfer by natural convection.

[0831] Material 494 may be or include molten salts such as solar salt, salts presented in Table 1, or other salts. The molten salts may be infrared transparent to aid in heat transfer from the insulated conductor to the canister. In some embodiments, solar salt includes sodium nitrate and potassium nitrate (for example, about 60% by weight sodium nitrate and about 40% by weight potassium nitrate). Solar salt melts at about 220 °C and is chemically stable up to temperatures of about 593 °C. Other salts that may be used include, but are not limited to $LiNO_3$ (melt temperature (T_m) of 264 °C and a decomposition temperature of about 600 °C) and eutectic mixtures such as 53% by weight KNO_3, 40% by weight $NaNO_3$ and 7% by weight $NaNO_2$ (T_m of about 142 °C and an upper working temperature of over 500 °C); 45.5% by weight KNO_3 and 54.5% by weight $NaNO_2$ (T_m of about 142-145 °C and an upper working temperature of over 500 °C); or 50% by weight NaCl and 50% by weight $SrCl_2$ (T_m of about 19 °C and an upper working temperature of over 1200 °C).

TABLE 1

Material	T_m (°C)	T_b (°C)
Zn	420	907
$CdBr_2$	568	863
CdI_2	388	744
$CuBr_2$	498	900
$PbBr_2$	371	892
TlBr	460	819
TlF	326	826

Material	T_m (°C)	T_b (°C)
ThI_4	566	837
SnF_2	215	850
SnI_2	320	714
$ZnCl_2$	290	732

[0832] Some molten salts, such as solar salt, may be relatively non-corrosive so that the conduit and/or the jacket may be made of relatively inexpensive material (for example, carbon steel). Some molten salts may have good thermal conductivity, may have high heat density, and may result in large heat transfer by natural convection.

[0833] In fluid mechanics, the Rayleigh number is a dimensionless number associated with heat transfer in a fluid. When the Rayleigh number is below the critical value for the fluid, heat transfer is primarily in the form of conduction; and when the Rayleigh number is above the critical value, heat transfer is primarily in the form of convection. The Rayleigh number is the product of the Grashof number (which describes the relationship between buoyancy and viscosity in a fluid) and the Prandtl number (which describes the relationship between momentum diffusivity and thermal diffusivity). For the same size insulated conductors in conduits, and where the temperature of the conduit is 500 °C, the Rayleigh number for solar salt in the conduit is about 10 times the Rayleigh number for tin in the conduit. The higher Rayleigh number implies that the strength of natural convection in the molten solar salt is much stronger than the strength of the natural convection in molten tin. The stronger natural convection of molten salt may distribute heat and inhibit the formation of hot spots at locations along the length of the conduit. Hot spots may be caused by coke build up at isolated locations adjacent to or on the conduit, contact of the conduit by the formation at isolated locations, and/or other high thermal load situations.

[0834] Conduit 382 may be a carbon steel or stainless steel canister. In some embodiments, conduit 382 may include cladding on the outer surface to inhibit corrosion of the conduit by formation fluid. Conduit 382 may include cladding on an inner surface of the conduit that is corrosion resistant to material 494 in the conduit. Cladding applied to conduit 382 may be a coating and/or a liner. If the conduit contains a metal salt, the inner surface of the conduit may include coating of nickel, or the conduit may be or include a liner of a corrosion resistant metal such as Alloy N. If the conduit contains a molten metal, the conduit may include a corrosion resistant metal liner or coating, and/or a ceramic coating (for example, a porcelain coating or fired enamel coating). In an embodiment, conduit 382 is a canister of 410 stainless steel with an outside diameter of about 6 cm. Conduit 382 may not need a thick wall because material 494

may provide internal pressure that inhibits deformation or crushing of the conduit due to external stresses.

[0835] FIG. 78 depicts an embodiment of the heater positioned in wellbore 490 of formation 492 with a portion of insulated conductor 410 and conduit 382 oriented substantially horizontally in the formation. Material 494 may provide a head in conduit 382 due to the pressure of the material. The pressure head may keep material 494 in conduit 382. The pressure head may also provide internal pressure that inhibits deformation or collapse of conduit 382 due to external stresses.

[0836] In some embodiments, two or more insulated conductors are placed in the conduit. In some embodiments, only one of the insulated conductors is energized. Should the energized conductor fail, one of the other conductors may be energized to maintain the material in a molten phase. The failed insulated conductor may be removed and/or replaced.

[0837] The conduit of the heater may be a ribbed conduit. The ribbed conduit may improve the heat transfer characteristics of the conduit as compared to a cylindrical conduit. FIG. 79 depicts a cross-sectional representation of ribbed conduit 496. FIG. 80 depicts a perspective view of a portion of ribbed conduit 496. Ribbed conduit 496 may include rings 498 and ribs 500. Rings 498 and ribs 500 may improve the heat transfer characteristics of ribbed conduit 496. In an embodiment, the cylinder of conduit has an inner diameter of about 5.1 cm and a wall thickness of about 0.57 cm. Rings 498 may be spaced about every 3.8 cm. Rings 498 may have a height of about 1.9 cm and a thickness of about 0.5 cm. Six ribs 500 may be spaced evenly about conduit 382. Ribs 500 may have a thickness of about 0.5 cm and a height of about 1.6 cm. Other dimensions for the cylinder, rings and ribs may be used. Ribbed conduit 496 may be formed from two or more rolled pieces that are welded together to form the ribbed conduit. Other types of conduit with extra surface area to enhance heat transfer from the conduit to the formation may be used.

[0838] In some embodiments, the ribbed conduit may be used as the conduit of a conductor-in-conduit heater. For example, the conductor may be a 3.05 cm 410 stainless steel rod and the conduit has dimensions as described above. In other embodiments, the conductor is an insulated conductor and a fluid is positioned between the conductor and the ribbed conduit. The fluid may be a gas or liquid at operating temperatures of the insulated conductor.

[0839] In some embodiments, the heat source for the heater is not an insulated conductor. For example, the heat source may be hot fluid circulated through an inner conduit positioned in an outer conduit. The material may be positioned between the inner conduit and the outer conduit. Convection currents in the material may help to more evenly distribute heat to the formation and may inhibit or limit formation of a hot spot where insulation that limits heat transfer to the

overburden ends. In some embodiments, the heat sources are downhole oxidizers. The material is placed between an outer conduit and an oxidizer conduit. The oxidizer conduit may be an exhaust conduit for the oxidizers or the oxidant conduit if the oxidizers are positioned in a u-shaped wellbore with exhaust gases exiting the formation through one of the legs of the u-shaped conduit. The material may help inhibit the formation of hot spots adjacent to the oxidizers of the oxidizer assembly.

[0840] The material to be heated by the insulated conductor may be placed in an open wellbore. FIG. 81 depicts material 494 in open wellbore 490 in formation 492 with insulated conductor 410 in the wellbore. In some embodiments, a gas (for example, nitrogen, carbon dioxide, and/or helium) is placed in wellbore 490 above material 494. The gas may inhibit oxidation or other chemical changes of material 494. The gas may inhibit vaporization of material 494.

[0841] Material 494 may have a melting point that is above the pyrolysis temperature of hydrocarbons in the formation. The melting point of material 494 may be above 375 °C, above 400 °C, or above 425 °C. The insulated conductor may be energized to heat the formation. Heat from the insulated conductor may pyrolyze hydrocarbons in the formation. Adjacent the wellbore, the heat from insulated conductor 410 may result in coking that reduces the permeability and plugs the formation near wellbore 490. The plugged formation inhibits material 494 from leaking from wellbore 490 into formation 492 when the material is a liquid. In some embodiments, material 494 is a salt.

[0842] In some embodiments, material 494 leaking from wellbore 490 into formation 492 may be self-healing and/or self-sealing. Material 494 flowing away from wellbore 490 may travel until the temperature becomes less than the solidification temperature of the material. Temperature may drop rapidly a relatively small distance away from the heater used to maintain material 494 in a liquid state. The rapid drop off in temperature may result in migrating material 494 solidifying close to wellbore 490. Solidified material 494 may inhibit migration of additional material from wellbore 490, and thus self-heal and/or self-seal the wellbore.

[0843] Return electrical current for insulated conductor 410 may return through jacket 370 of the insulated conductor. Any current that passes through material 494 may pass to ground. Above the level of material 494, any remaining return electrical current may be confined to jacket 370 of insulated conductor 410.

[0844] Using liquid material in open wellbores heated by heaters may allow for delivery of high power rates (for example, up to about 2000 W/m) to the formation with relatively low heater surface temperatures. Hot spot generation in the formation may be reduced or eliminated due to convection smoothing out the temperature profile along the length of the heater. Natural convection occurring in the wellbore may greatly enhance heat transfer from the heater to the

formation. Also, the large gap between the formation and the heater may prevent thermal expansion of the formation from harming the heater.

[0845] In some embodiments, an 8 inch (20.3 cm) wellbore may be formed in the formation. In some embodiments, casing may be placed through all or a portion of the overburden. A 0.6 inch (1.5 cm) diameter insulated conductor heater may be placed in the wellbore. The wellbore may be filled with solid material (for example, solid particles of salt). A packer may be placed near an interface between the treatment area and the overburden. In some embodiments, a pass through conduit in the packer may be included to allow for the addition of more material to the treatment area. A non-reactive or substantially non-reactive gas (for example, carbon dioxide and/or nitrogen) may be introduced into the wellbore. The insulated conductor may be energized to begin the heating that melts the solid material and heats the treatment area.

[0846] In some embodiments, other types of heat sources besides for insulated conductors are used to heat the material placed in the open wellbore. The other types of heat sources may include gas burners, pipes through which hot heat transfer fluid flows, or other types of heaters.

[0847] In some embodiments, heat pipes are placed in the formation. The heat pipes may reduce the number of active heat sources needed to heat a treatment area of a given size. The heat pipes may reduce the time needed to heat the treatment area of a given size to a desired average temperature. A heat pipe is a closed system that utilizes phase change of fluid in the heat pipe to transport heat applied to a first region to a second region remote from the first region. The phase change of the fluid allows for large heat transfer rates. Heat may be applied to the first region of the heat pipes from any type of heat source, including but not limited to, electric heaters, oxidizers, heat provided from geothermal sources, and/or heat provided from nuclear reactors.

[0848] Heat pipes are passive heat transport systems that include no moving parts. Heat pipes may be positioned in near horizontal to vertical configurations. The fluid used in heat pipes for heating the formation may have a low cost, a low melting temperature, a boiling temperature that is not too high (for example, generally below about 900 °C), a low viscosity at temperatures below about 540 °C, a high heat of vaporization, and a low corrosion rate for the heat pipe material. In some embodiments, the heat pipe includes a liner of material that is resistant to corrosion by the fluid. TABLE 1 shows melting and boiling temperatures for several materials that may be used as the fluid in heat pipes. Other salts that may be used include, but are not limited to $LiNO_3$, and eutectic mixtures such as 53% by weight KNO_3; 40% by weight $NaNO_3$ and 7% by weight $NaNO_2$; 45.5% by weight KNO_3 and 54.5% by weight $NaNO_2$; or 50% by weight NaCl and 50% by weight $SrCl_2$.

[0849] FIG. 82 depicts schematic cross-sectional representation of a portion of a formation with heat pipes 502 positioned adjacent to a substantially horizontal portion of heat source 202. Heat

source 202 is placed in a wellbore in the formation. Heat source 202 may be a gas burner assembly, an electrical heater, a leg of a circulation system that circulates hot fluid through the formation, or other type of heat source. Heat pipes 502 may be placed in the formation so that distal ends of the heat pipes are near or contact heat source 202. In some embodiments, heat pipes 502 mechanically attach to heat source 202. Heat pipes 502 may be spaced a desired distance apart. In an embodiment, heat pipes 502 are spaced apart by about 40 feet. In other embodiments, large or smaller spacings are used. Heat pipes 502 may be placed in a regular pattern with each heat pipe spaced a given distance from the next heat pipe. In some embodiments, heat pipes 502 are placed in an irregular pattern. An irregular pattern may be used to provide a greater amount of heat to a selected portion or portions of the formation. Heat pipes 502 may be vertically positioned in the formation. In some embodiments, heat pipes 502 are placed at an angle in the formation.

[0850] Heat pipes 502 may include sealed conduit 504, seal 506, liquid heat transfer fluid 508 and vaporized heat transfer fluid 510. In some embodiments, heat pipes 502 include metal mesh or wicking material that increases the surface area for condensation and/or promotes flow of the heat transfer fluid in the heat pipe. Conduit 504 may have first portion 512 and second portion 514. Liquid heat transfer fluid 508 may be in first portion 512. Heat source 202 external to heat pipe 502 supplies heat that vaporizes liquid heat transfer fluid 508. Vaporized heat transfer fluid 510 diffuses into second portion 514. Vaporized heat transfer fluid 510 condenses in second portion and transfers heat to conduit 504, which in turn transfers heat to the formation. The condensed liquid heat transfer fluid 508 flows by gravity to first portion 512.

[0851] Position of seal 506 is a factor in determining the effective length of heat pipe 502. The effective length of heat pipe 502 may also depend on the physical properties of the heat transfer fluid and the cross-sectional area of conduit 504. Enough heat transfer fluid may be placed in conduit 504 so that some liquid heat transfer fluid 508 is present in first portion 512 at all times.

[0852] Seal 506 may provide a top seal for conduit 504. In some embodiments, conduit 504 is purged with nitrogen, helium or other fluid prior to being loaded with heat transfer fluid and sealed. In some embodiments, a vacuum may be drawn on conduit 504 to evacuate the conduit before the conduit is sealed. Drawing a vacuum on conduit 504 before sealing the conduit may enhance vapor diffusion throughout the conduit. In some embodiments, an oxygen getter may be introduced in conduit 504 to react with any oxygen present in the conduit.

[0853] FIG. 83 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with heat pipe 502 located radially around oxidizer assembly 516. Oxidizers 518 of oxidizer assembly 516 are positioned adjacent to first portion 512 of heat pipe 502. Fuel may be supplied to oxidizers 518 through fuel conduit 520. Oxidant may be supplied to oxidizers 518

through oxidant conduit 522. Exhaust gas may flow through the space between outer conduit 524 and oxidant conduit 522. Oxidizers 518 combust fuel to provide heat that vaporizes liquid heat transfer fluid 508. Vaporized heat transfer fluid 510 rises in heat pipe 502 and condenses on walls of the heat pipe to transfer heat to sealed conduit 504. Exhaust gas from oxidizers 518 provides heat along the length of sealed conduit 504. The heat provided by the exhaust gas along the effective length of heat pipe 502 may increase convective heat transfer and/or reduce the lag time before significant heat is provided to the formation from the heat pipe along the effective length of the heat pipe.

[0854] FIG. 84 depicts a cross-sectional representation of an angled heat pipe embodiment with oxidizer assembly 516 located near a lowermost portion of heat pipe 502. Fuel may be supplied to oxidizers 518 through fuel conduit 520. Oxidant may be supplied to oxidizers 518 through oxidant conduit 522. Exhaust gas may flow through the space between outer conduit 524 and oxidant conduit 522.

[0855] FIG. 85 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with oxidizer 518 located at the bottom of heat pipe 502. Fuel may be supplied to oxidizer 518 through fuel conduit 520. Oxidant may be supplied to oxidizer 518 through oxidant conduit 522. Exhaust gas may flow through the space between the outer wall of heat pipe 502 and outer conduit 524. Oxidizer 518 combusts fuel to provide heat that vaporizers liquid heat transfer fluid 508. Vaporized heat transfer fluid 510 rises in heat pipe 502 and condenses on walls of the heat pipe to transfer heat to sealed conduit 504. Exhaust gas from oxidizers 518 provides heat along the length of sealed conduit 504 and to outer conduit 524. The heat provided by the exhaust gas along the effective length of heat pipe 502 may increase convective heat transfer and/or reduce the lag time before significant heat is provided to the formation from the heat pipe and oxidizer combination along the effective length of the heat pipe. FIG. 86 depicts a similar embodiment with heat pipe 502 positioned at an angle in the formation.

[0856] FIG. 87 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with oxidizer 518 that produces flame zone adjacent to liquid heat transfer fluid 508 in the bottom of heat pipe 502. Fuel may be supplied to oxidizer 518 through fuel conduit 520. Oxidant may be supplied to oxidizer 518 through oxidant conduit 522. Oxidant and fuel are mixed and combusted to produce flame zone 526. Flame zone 526 provides heat that vaporizes liquid heat transfer fluid 508. Exhaust gases from oxidizer 518 may flow through the space between oxidant conduit 522 and the inner surface of heat pipe 502, and through the space between the outer surface of the heat pipe and outer conduit 524. The heat provided by the exhaust gas along the effective length of heat pipe 502 may increase convective heat transfer

and/or reduce the lag time before significant heat is provided to the formation from the heat pipe and oxidizer combination along the effective length of the heat pipe.

[0857] FIG. 88 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with a tapered bottom that accommodates multiple oxidizers of an oxidizer assembly. In some embodiments, efficient heat pipe operation requires a high heat input. Multiple oxidizers of oxidizer assembly 516 may provide high heat input to liquid heat transfer fluid 508 of heat pipe 502. A portion of oxidizer assembly with the oxidizers may be helically wound around a tapered portion of heat pipe 502. The tapered portion may have a large surface area to accommodate the oxidizers. Fuel may be supplied to the oxidizers of oxidizer assembly 516 through fuel conduit 520. Oxidant may be supplied to oxidizer 518 through oxidant conduit 522. Exhaust gas may flow through the space between the outer wall of heat pipe 502 and outer conduit 524. Exhaust gas from oxidizers 518 provides heat along the length of sealed conduit 504 and to outer conduit 524. The heat provided by the exhaust gas along the effective length of heat pipe 502 may increase convective heat transfer and/or reduce the lag time before significant heat is provided to the formation from the heat pipe and oxidizer combination along the effective length of the heat pipe.

[0858] FIG. 89 depicts a cross-sectional representation of a heat pipe embodiment that is angled within the formation. First wellbore 528 and second wellbore 530 are drilled in the formation using magnetic ranging or techniques so that the first wellbore intersects the second wellbore. Heat pipe 502 may be positioned in first wellbore 528. First wellbore 528 may be sloped so that liquid heat transfer fluid 508 within heat pipe 502 is positioned near the intersection of the first wellbore and second wellbore 530. Oxidizer assembly 516 may be positioned in second wellbore 530. Oxidizer assembly 516 provides heat to heat pipe 502 that vaporizes liquid heat transfer fluid in the heat pipe. Packer or seal 532 may direct exhaust gas from oxidizer assembly 516 through first wellbore 528 to provide additional heat to the formation from the exhaust gas.

[0859] In some embodiments, the temperature limited heater is used to achieve lower temperature heating (for example, for heating fluids in a production well, heating a surface pipeline, or reducing the viscosity of fluids in a wellbore or near wellbore region). Varying the ferromagnetic materials of the temperature limited heater allows for lower temperature heating. In some embodiments, the ferromagnetic conductor is made of material with a lower Curie temperature than that of 446 stainless steel. For example, the ferromagnetic conductor may be an alloy of iron and nickel. The alloy may have between 30% by weight and 42% by weight nickel with the rest being iron. In one embodiment, the alloy is Invar 36. Invar 36 is 36% by weight nickel in iron and has a Curie temperature of 277 °C. In some embodiments, an alloy is a three component alloy with, for example, chromium, nickel, and iron. For example, an alloy may have

6% by weight chromium, 42% by weight nickel, and 52% by weight iron. A 2.5 cm diameter rod of Invar 36 has a turndown ratio of approximately 2 to 1 at the Curie temperature. Placing the Invar 36 alloy over a copper core may allow for a smaller rod diameter. A copper core may result in a high turndown ratio. The insulator in lower temperature heater embodiments may be made of a high performance polymer insulator (such as PFA or PEEK™) when used with alloys with a Curie temperature that is below the melting point or softening point of the polymer insulator.

[0860] In certain embodiments, a conductor-in-conduit temperature limited heater is used in lower temperature applications by using lower Curie temperature and/or the phase transformation temperature range ferromagnetic materials. For example, a lower Curie temperature and/or the phase transformation temperature range ferromagnetic material may be used for heating inside sucker pump rods. Heating sucker pump rods may be useful to lower the viscosity of fluids in the sucker pump or rod and/or to maintain a lower viscosity of fluids in the sucker pump rod. Lowering the viscosity of the oil may inhibit sticking of a pump used to pump the fluids. Fluids in the sucker pump rod may be heated up to temperatures less than about 250 °C or less than about 300 °C. Temperatures need to be maintained below these values to inhibit coking of hydrocarbon fluids in the sucker pump system.

[0861] In certain embodiments, a temperature limited heater includes a flexible cable (for example, a furnace cable) as the inner conductor. For example, the inner conductor may be a 27% nickel-clad or stainless steel-clad stranded copper wire with four layers of mica tape surrounded by a layer of ceramic and/or mineral fiber (for example, alumina fiber, aluminosilicate fiber, borosilicate fiber, or aluminoborosilicate fiber). A stainless steel-clad stranded copper wire furnace cable may be available from Anomet Products, Inc. The inner conductor may be rated for applications at temperatures of 1000 °C or higher. The inner conductor may be pulled inside a conduit. The conduit may be a ferromagnetic conduit (for example, a ¾" Schedule 80 446 stainless steel pipe). The conduit may be covered with a layer of copper, or other electrical conductor, with a thickness of about 0.3 cm or any other suitable thickness. The assembly may be placed inside a support conduit (for example, a 1-¼" Schedule 80 347H or 347HH stainless steel tubular). The support conduit may provide additional creep-rupture strength and protection for the copper and the inner conductor. For uses at temperatures greater than about 1000 °C, the inner copper conductor may be plated with a more corrosion resistant alloy (for example, Incoloy® 825) to inhibit oxidation. In some embodiments, the top of the temperature limited heater is sealed to inhibit air from contacting the inner conductor.

[0862] FIG. 90 depicts an embodiment of three heaters coupled in a three-phase configuration. Conductor "legs" 534, 536, 538 are coupled to three-phase transformer 414. Transformer 414

may be an isolated three-phase transformer. In certain embodiments, transformer 414 provides three-phase output in a wye configuration. Input to transformer 414 may be made in any input configuration, such as the shown delta configuration. Legs 534, 536, 538 each include lead-in conductors 540 in the overburden of the formation coupled to heating elements 542 in hydrocarbon layer 388. Lead-in conductors 540 include copper with an insulation layer. For example, lead-in conductors 540 may be a 4-0 copper cables with TEFLON® insulation, a copper rod with polyurethane insulation, or other metal conductors such as bare copper or aluminum. In certain embodiments, lead-in conductors 540 are located in an overburden portion of the formation. The overburden portion may include overburden casings 398. Heating elements 542 may be temperature limited heater heating elements. In an embodiment, heating elements 542 are 410 stainless steel rods (for example, 3.1 cm diameter 410 stainless steel rods). In some embodiments, heating elements 542 are composite temperature limited heater heating elements (for example, 347 stainless steel, 410 stainless steel, copper composite heating elements; 347 stainless steel, iron, copper composite heating elements; or 410 stainless steel and copper composite heating elements). In certain embodiments, heating elements 542 have a length of about 10 m to about 2000 m, about 20 m to about 400 m, or about 30 m to about 300 m.

[0863] In certain embodiments, heating elements 542 are exposed to hydrocarbon layer 388 and fluids from the hydrocarbon layer. Thus, heating elements 542 are "bare metal" or "exposed metal" heating elements. Heating elements 542 may be made from a material that has an acceptable sulfidation rate at high temperatures used for pyrolyzing hydrocarbons. In certain embodiments, heating elements 542 are made from material that has a sulfidation rate that decreases with increasing temperature over at least a certain temperature range (for example, 500 °C to 650 °C, 530 °C to 650 °C, or 550 °C to 650 °C). For example, 410 stainless steel may have a sulfidation rate that decreases with increasing temperature between 530 °C and 650 °C. Using such materials reduces corrosion problems due to sulfur-containing gases (such as H_2S) from the formation. In certain embodiments, heating elements 542 are made from material that has a sulfidation rate below a selected value in a temperature range. In some embodiments, heating elements 542 are made from material that has a sulfidation rate at most about 25 mils per year at a temperature between about 800 °C and about 880 °C. In some embodiments, the sulfidation rate is at most about 35 mils per year at a temperature between about 800 °C and about 880 °C, at most about 45 mils per year at a temperature between about 800 °C and about 880 °C, or at most about 55 mils per year at a temperature between about 800 °C and about 880 °C. Heating elements 542 may also be substantially inert to galvanic corrosion.

[0864] In some embodiments, heating elements 542 have a thin electrically insulating layer such as aluminum oxide or thermal spray coated aluminum oxide. In some embodiments, the thin

electrically insulating layer is a ceramic composition such as an enamel coating. Enamel coatings include, but are not limited to, high temperature porcelain enamels. High temperature porcelain enamels may include silicon dioxide, boron oxide, alumina, and alkaline earth oxides (CaO or MgO), and minor amounts of alkali oxides (Na_2O, K_2O, LiO). The enamel coating may be applied as a finely ground slurry by dipping the heating element into the slurry or spray coating the heating element with the slurry. The coated heating element is then heated in a furnace until the glass transition temperature is reached so that the slurry spreads over the surface of the heating element and makes the porcelain enamel coating. The porcelain enamel coating contracts when cooled below the glass transition temperature so that the coating is in compression. Thus, when the coating is heated during operation of the heater, the coating is able to expand with the heater without cracking.

[0865] The thin electrically insulating layer has low thermal impedance allowing heat transfer from the heating element to the formation while inhibiting current leakage between heating elements in adjacent openings and/or current leakage into the formation. In certain embodiments, the thin electrically insulating layer is stable at temperatures above at least 350 °C, above 500 °C, or above 800 °C. In certain embodiments, the thin electrically insulating layer has an emissivity of at least 0.7, at least 0.8, or at least 0.9. Using the thin electrically insulating layer may allow for long heater lengths in the formation with low current leakage.

[0866] Heating elements 542 may be coupled to contacting elements 544 at or near the underburden of the formation. Contacting elements 544 are copper or aluminum rods or other highly conductive materials. In certain embodiments, transition sections 546 are located between lead-in conductors 540 and heating elements 542, and/or between heating elements 542 and contacting elements 544. Transition sections 546 may be made of a conductive material that is corrosion resistant such as 347 stainless steel over a copper core. In certain embodiments, transition sections 546 are made of materials that electrically couple lead-in conductors 540 and heating elements 542 while providing little or no heat output. Thus, transition sections 546 help to inhibit overheating of conductors and insulation used in lead-in conductors 540 by spacing the lead-in conductors from heating elements 542. Transition section 546 may have a length of between about 3 m and about 9 m (for example, about 6 m).

[0867] Contacting elements 544 are coupled to contactor 548 in contacting section 550 to electrically couple legs 534, 536, 538 to each other. In some embodiments, contact solution 552 (for example, conductive cement) is placed in contacting section 550 to electrically couple contacting elements 544 in the contacting section. In certain embodiments, legs 534, 536, 538 are substantially parallel in hydrocarbon layer 388 and leg 534 continues substantially vertically

into contacting section 550. The other two legs 536, 538 are directed (for example, by directionally drilling the wellbores for the legs) to intercept leg 534 in contacting section 550.

[0868] Each leg 534, 536, 538 may be one leg of a three-phase heater embodiment so that the legs are substantially electrically isolated from other heaters in the formation and are substantially electrically isolated from the formation. Legs 534, 536, 538 may be arranged in a triangular pattern so that the three legs form a triangular shaped three-phase heater. In an embodiment, legs 534, 536, 538 are arranged in a triangular pattern with 12 m spacing between the legs (each side of the triangle has a length of 12 m).

[0869] FIG. 91 depicts a side view representation of an embodiment of a substantially u-shaped three-phase heater. First ends of legs 534, 536, 538 are coupled to transformer 414 at first location 554. In an embodiment, transformer 414 is a three-phase AC transformer. Ends of legs 534, 536, 538 are electrically coupled together with connector 556 at second location 558. Connector 556 electrically couples the ends of legs 534, 536, 538 so that the legs can be operated in a three-phase configuration. In certain embodiments, legs 534, 536, 538 are coupled to operate in a three-phase wye configuration. In certain embodiments, legs 534, 536, 538 are substantially parallel in hydrocarbon layer 388. In certain embodiments, legs 534, 536, 538 are arranged in a triangular pattern in hydrocarbon layer 388. In certain embodiments, heating elements 542 include thin electrically insulating material (such as a porcelain enamel coating) to inhibit current leakage from the heating elements. In certain embodiments, the thin electrically insulating layer allows for relatively long, substantially horizontal heater leg lengths in the hydrocarbon layer with a substantially u-shaped heater. In certain embodiments, legs 534, 536, 538 are electrically coupled so that the legs are substantially electrically isolated from other heaters in the formation and are substantially electrically isolated from the formation.

[0870] In certain embodiments, overburden casings (for example, overburden casings 398, depicted in FIGS. 90 and 91) in overburden 400 include materials that inhibit ferromagnetic effects in the casings. Inhibiting ferromagnetic effects in casings 398 reduces heat losses to the overburden. In some embodiments, casings 398 may include non-metallic materials such as fiberglass, polyvinylchloride (PVC), chlorinated polyvinylchloride (CPVC), or high-density polyethylene (HDPE). HDPEs with working temperatures in a range for use in overburden 400 include HDPEs available from Dow Chemical Co., Inc. (Midland, Michigan, U.S.A.). A non-metallic casing may also eliminate the need for an insulated overburden conductor. In some embodiments, casings 398 include carbon steel coupled on the inside diameter of a non-ferromagnetic metal (for example, carbon steel clad with copper or aluminum) to inhibit ferromagnetic effects or inductive effects in the carbon steel. Other non-ferromagnetic metals include, but are not limited to, manganese steels with at least 10% by weight manganese, iron

aluminum alloys with at least 18% by weight aluminum, and austentitic stainless steels such as 304 stainless steel or 316 stainless steel.

[0871] In certain embodiments, one or more non-ferromagnetic materials used in casings 398 are used in a wellhead coupled to the casings and legs 534, 536, 538. Using non-ferromagnetic materials in the wellhead inhibits undesirable heating of components in the wellhead. In some embodiments, a purge gas (for example, carbon dioxide, nitrogen or argon) is introduced into the wellhead and/or inside of casings 398 to inhibit reflux of heated gases into the wellhead and/or the casings.

[0872] In certain embodiments, one or more of legs 534, 536, 538 are installed in the formation using coiled tubing. In certain embodiments, coiled tubing is installed in the formation, the leg is installed inside the coiled tubing, and the coiled tubing is pulled out of the formation to leave the leg installed in the formation. The leg may be placed concentrically inside the coiled tubing. In some embodiments, coiled tubing with the leg inside the coiled tubing is installed in the formation and the coiled tubing is removed from the formation to leave the leg installed in the formation. The coiled tubing may extend only to a junction of the hydrocarbon layer and the contacting section, or to a point at which the leg begins to bend in the contacting section.

[0873] FIG. 92 depicts a top view representation of an embodiment of a plurality of triads of three-phase heaters in the formation. Each triad 560 includes legs A, B, C (which may correspond to legs 534, 536, 538 depicted in FIGS. 90 and 91) that are electrically coupled by linkages 562. Each triad 560 is coupled to its own electrically isolated three-phase transformer so that the triads are substantially electrically isolated from each other. Electrically isolating the triads inhibits net current flow between triads.

[0874] The phases of each triad 560 may be arranged so that legs A, B, C correspond between triads as shown in FIG. 92. Legs A, B, C are arranged such that a phase leg (for example, leg A) in a given triad is about two triad heights from a same phase leg (leg A) in an adjacent triad. The triad height is the distance from a vertex of the triad to a midpoint of the line intersecting the other two vertices of the triad. In certain embodiments, the phases of triads 560 are arranged to inhibit net current flow between individual triads. There may be some leakage of current within an individual triad but little net current flows between two triads due to the substantial electrical isolation of the triads and, in certain embodiments, the arrangement of the triad phases.

[0875] In the early stages of heating, an exposed heating element (for example, heating element 542 depicted in FIGS. 90 and 91) may leak some current to water or other fluids that are electrically conductive in the formation so that the formation itself is heated. After water or other electrically conductive fluids are removed from the wellbore (for example, vaporized or produced), the heating elements become electrically isolated from the formation. Later, when

water is removed from the formation, the formation becomes even more electrically resistant and heating of the formation occurs even more predominantly via thermally conductive and/or radiative heating. Typically, the formation (the hydrocarbon layer) has an initial electrical resistance that averages at least 10 ohm·m. In some embodiments, the formation has an initial electrical resistance of at least 100 ohm·m or of at least 300 ohm·m.

[0876] Using the temperature limited heaters as the heating elements limits the effect of water saturation on heater efficiency. With water in the formation and in heater wellbores, there is a tendency for electrical current to flow between heater elements at the top of the hydrocarbon layer where the voltage is highest and cause uneven heating in the hydrocarbon layer. This effect is inhibited with temperature limited heaters because the temperature limited heaters reduce localized overheating in the heating elements and in the hydrocarbon layer.

[0877] In certain embodiments, production wells are placed at a location at which there is relatively little or zero voltage potential. This location minimizes stray potentials at the production well. Placing production wells at such locations improves the safety of the system and reduces or inhibits undesired heating of the production wells caused by electrical current flow in the production wells. FIG. 93 depicts a top view representation of the embodiment depicted in FIG. 92 with production wells 206. In certain embodiments, production wells 206 are located at or near center of triad 560. In certain embodiments, production wells 206 are placed at a location between triads at which there is relatively little or zero voltage potential (at a location at which voltage potentials from vertices of three triads average out to relatively little or zero voltage potential). For example, production well 206 may be at a location equidistant from leg A of one triad, leg B of a second triad, and leg C of a third triad, as shown in FIG. 93.

[0878] Certain embodiments of heaters include conducting elements from an AC power supply in a single wellbore. For example, FIGS. 90 and 91 depict heater embodiments with three-phase heaters that include single conducting elements carrying one of the three phases in each wellbore. The single conducting element may carry, for example, a single-phase (one phase) of the three-phase heater. A problem with having a single conducting element in the wellbore is current or voltage induction in conductors on the surface, components of the wellbore (for example, the heater casing), and/or in the formation caused by magnetic fields produced by the single conducting element. In a wellbore with the supply and return conductors both located in the wellbore, the magnetic fields produced by the current running through the supply conductor are cancelled by magnetic fields produced by the current running through the return conductor. In addition, the single conducting element may induce currents in production wellbores and/or other nearby wellbores.

[0879] FIG. 94 depicts a schematic of an embodiment of a heat treatment system including heater 412 and production wells 206. In certain embodiments, heater 412 is a three-phase heater that includes legs 534, 536, 538 coupled to transformer 414 delivering three-phase power and terminal connector 556. Legs 534, 536, 538 may each include single conducting elements carrying one phase of the three-phase power. Legs 534, 536, 538 may be coupled together to form a "triad" heater. In certain embodiments, legs 534, 536, 538 are relatively long heater sections. For example, legs 534, 536, 538 may be about 3000 m or longer in length.

[0880] In some embodiments, as shown in FIG. 94, production wells 206 are located substantially horizontally in the formation in proximity to legs 534, 536, 538 of heater 412 in order to collect heated formation fluids or other formation fluids. In some embodiments, production wells 206 may be other types of wells such as injection wells or monitoring wells. In some embodiments, production wells 206 are located at an incline or vertically in the formation. As shown in FIG. 94, production wells 206 may include two production wells that extend from each side of heater 412 towards the center of the heater substantially lengthwise along the heated sections of legs 534, 536, 538. In some embodiments, one production well 206 extends substantially lengthwise along the heated sections of the legs.

[0881] FIG. 95 depicts a side-view representation of one leg of heater 412 in the subsurface formation. Leg 534 is shown as representative of any leg in of heater 412 in the formation. Leg 534 may include heating element 542 in hydrocarbon layer 388 below overburden 400. In certain embodiments, heating element 542 is located substantially horizontal in hydrocarbon layer 388. Transition section 546 may couple heating element 542 to lead-in cable 540. Lead-in cable 540 may be an overburden section or overburden element of heater 412. Lead-in cable 540 couples heating element 542 and transition section 546 to electrical components at the surface (for example, transformer 414 and/or terminal connector 556 depicted in FIG. 94).

[0882] As shown in FIG. 95, heater casing 564 extends from the surface to at or near end of transition section 546. Overburden casing 398 substantially surrounds heater casing 564 in overburden 400. Surface conductor 566 substantially surrounds overburden casing 398 at or near the surface of the formation.

[0883] In certain embodiments, heating element 542 is an exposed metal or bare metal heating element. For example, heating element 542 may be an exposed ferromagnetic metal heating element such as 410 stainless steel. Lead-in cable 540 includes low resistance electrical conductors such as copper or copper-clad steel. Lead-in cable 540 may include electrical insulation or otherwise be electrically insulated from overburden 400 (for example, overburden casing 398 may include electrical insulation on an inside surface of the casing). Transition

section 546 may include a combination of stainless steel and copper suitable for transition between heating element 542 and lead-in cable 540.

[0884] In some embodiments, heater casing 564 includes non-ferromagnetic stainless steel or another suitable material that has high hanging strength and is non-ferromagnetic. Overburden casing 398 and/or surface conductor 566 may include carbon steel or other suitable materials.

[0885] FIG. 96 depicts a schematic representation of a surface cabling configuration with a ground loop used for heater 412 and production well 206. In certain embodiments, ground loop 568 substantially surrounds legs 534, 536, 538 of heater 412, production well 206, and transformer 414. Power cable 394 may couple transformer 414 to legs 534, 536, 538 of heater 412. The center portion of power cable 394 coupled to the transformer neutral may be connected to loop 570. Loop 570 extends the center portion of power cable 394 to have approximately the same length as the portions of power cable 394 coupled to side legs 534, 538. Having each portion of power cable 394 approximately the same length inhibits creation of phase current differences between the legs.

[0886] In certain embodiments, transformer 414 is coupled to ground loop 568 to ground the transformer and heater 412. In some embodiments, transformer 414 is coupled to ground loop 568 through a high grounding resistance. Connection through the high grounding resistance may allow detection of ground faults while limiting fault currents. In some embodiments, production well 206 is coupled to ground loop 568 to ground the production well.

[0887] FIG. 97 depicts a side view of an overburden portion of leg 534. Lead-in cable 540 is substantially surrounded by heater casing 564 and overburden casing 398 ("casing 564/398") in the overburden of the formation. Current flow in lead-in cable 540 (represented by +/- symbols at ends the lead-in cable) induces a potential of opposite polarity on casing 564/398 (represented by +/- symbols on line 572). This induced voltage on casing 564/398 is caused by mutual inductance of the casing with all the heater elements in the triad (each of the three-phase elements in the formation). The mutual inductance may be described by the following equation:

(EQN. 6) $M = 2x10^{-07}\ln[S/r];$

where M is the mutual inductance, S is the center to center separation between heater elements, and r is the outer radius of the casing. The induced voltage (per unit length) in the casing (V) is proportional to the heater lead-in current (I) and is given by the equation:

(EQN. 7) $\Delta V = \omega MI.$

[0888] Because typically high current is provided through lead-in cable 540 in order to provide power to long heater elements, the induced voltages on casing 564/398 can be relatively high. The induced casing potential may drive large casing currents through a circuit that includes the casing and the associated conducting earth path. Large currents flowing from the casing to and

from the earth may lead to AC corrosion problems and/or leakage of current into the formation. Large currents on the casing, when grounded, may also necessitate large currents in the ground loop to compensate for the currents on the casing. Large currents on the ground loop may be costly in power consumption and, in some cases, be difficult or unsafe to operate. Induced casing potential and resulting casing currents may also lead to high surface potentials around the heaters on the surface. High surface potentials may create unsafe areas for personnel and/or equipment on the surface.

[0889] Simulations may be used to assess and/or determine the location and magnitude of induced casing and ground currents in the formation. For example, simulation systems available from Safe Engineering Services & Technologies, Ltd. (Laval, Quebec, Canada) may be used to assess induced casing and ground currents for subsurface heating systems. Data such as, but not limited to, physical dimensions of the heaters, electrical and magnetic properties of materials used, formation resistivity profile, and applied voltage/current including phase profile may be used in the simulation to assess induced casing and ground currents.

[0890] FIG. 98 depicts a side view of overburden portions of legs 534, 536 grounded to ground loop 568. Legs 534, 536 have opposite polarity such that the currents induced in the casings of the legs also have opposite polarity. The opposite polarity of the casings causes circulating current flow between the legs through the overburden. This circulating current flow is represented by curve 574. Because legs 534, 536 are grounded to ground loop 568, the magnitude of circulating current flow (curve 574) (current density on the casings) is relatively large. For example, normal current densities on the surface of the heater casing may be 1 A/m^2 or greater. Such current densities may increase the risk of AC corrosion in the heater casing.

[0891] FIG. 99 depicts a side view of overburden portions of legs 534, 536 with the legs ungrounded to a ground loop. Ungrounding legs 534, 536 reduces the magnitude of the circulating current flow between the legs (current density on the casings), as shown by curve 574. For example, the current density on the heater casing may be lowered by a factor of about 2. This reduction in magnitude may, however, not be large enough to satisfy regulatory and/or safety issues with the induced current as the induced current remains near the surface of the formation. In addition, there may be additional regulatory and/or safety issues associated with ungrounding legs 534, 536 such as, but not limited to, increasing wellhead electrical fields above safe levels.

[0892] FIG. 100 depicts a side view of overburden portions of legs 534, 536 with the electrically conductive portions of casings 564/398 lowered selected depth 576 below the surface. As shown by curve 574, lowering the conductive portion of casings 564/398 selected depth 576 reduces the magnitude of the induced current (and normal current density on the casings) and moves the

induced current to the selected depth below the surface. Moving the induced current to selected depth 576 below the surface reduces surface potentials and surface ground currents from the induced currents in the casings. For example, the normal current density on the heater casing may be lowered by a factor of about 3 by lowering the conductive portion of the casing.

[0893] In certain embodiments, the conductive portions of casings 564/398 are lowered in the formation by using electrically non-conductive materials in the portions of the casings above the conductive portions of the casings. For example, casings 564/398 may include non-conductive portions between the surface and the selected depth and conductive portions below the selected depth. In some embodiments, the electrically non-conductive portions include materials such as, but not limited to, fiberglass or other electrically insulating materials.

[0894] The non-conductive portion of casings 564/398 may only be used to the selected depth because the use of the non-conductive material may not be technically feasible or economically feasible for the entire depth of the casing. Materials to make non-conducting material are generally more expensive than materials to make the conductive portion (for example, stainless steel), thus it is desirable to minimize the size of the non-conductive portion of the casing. The non-conductive material may have low temperature limits that inhibit use of the non-conductive material near the heated section of the heater. Thus, conductive material may need to be used in the lower part of the overburden portion of the heater (the part near the heated section). As the non-conductive material may not be high strength material, to support the weight of the conductive material (for example, stainless steel), the conductive portion may be located as close to the surface as possible. Locating the conductive portion closer to the surface reduces the size of hanging devices or other structures that may be required to support the conductive portion of the casing during installation.

[0895] In certain embodiments, the non-conductive portion of casings 564/398 extends to a depth that is below the surface moisture zone in the formation. The surface moisture zone may be a portion of the overburden that contains materials or fluids (for example, water) that may conduct currents at or near the surface. For example, a surface moisture zone may be the portion of the formation that has a moisture content greater than the moisture content of the top soil. In some embodiments, a surface moisture zone has a resistivity of greater than 100 ohm m. Keeping the conductive portion of casings 564/398 below the surface moisture zone reduces the magnitude of induced currents at the surface. In some embodiments, the conductive portion of casing 564/398 is located below a layer that has a resistivity of greater than 100 ohm m.

[0896] In some embodiments, the non-conductive portion of casings 564/398 extends to a depth that is at least the distance between legs 534, 536. In certain embodiments, legs 534, 536 are in adjacent wellbores. The non-conductive portion of casings 564/398 extends to a depth that is at

least twice the distance of the spacing between legs. For example, for a 40' (about 12 m) spacing between legs, the non-conductive portion of casings 564/398 may extend at least about 100' (about 30 m) below the surface. In some embodiments, the non-conductive portion of casings 564/398 extends at least about 15 m, at least about 20 m, or at least about 30 m below the surface. The non-conductive portion of casings 564/398 may extend to a depth of at most about 150 m, about 300 m, or about 500 m from the surface. In some embodiments, the non-conducting portion extends to a depth that is greater than a distance between the heater wellbore and a closest additional heater wellbore in the formation. In some embodiments, legs 534, 536 are in adjacent wellbores in the formation. The non-conductive portion of casings 564/398 may extend to a depth that is at least twice the distance between the wellbores.

[0897] The non-conductive portion of casings 564/398 may extend at most to a selected distance from the heated zone of the formation (the heated portion of the heater). In some embodiments, the selected distance is about 100 m, about 150 m, or about 200 m. In some embodiments, the non-conductive portion of casings 564/398 may extend to a depth that is slightly above or near the beginning of the bend in a u-shaped heater.

[0898] The desired depth of non-conductive portion of casings 564/398 may be assessed based on electrical effects for the formation to be treated and/or electrical properties of the heaters to be used. Simulations, such as those available from Safe Engineering Services & Technologies, Ltd. (Laval, Quebec, Canada), may be used to assess the desired depth of the non-conductive portion of the casing. The desired depth may also be affected by factors such as, but not limited to, safety issues, regulatory issues, and mechanical issues.

[0899] In some embodiments, the overburden portions of legs 534, 536 are moved closer together so that the non-conductive portion of casings 564/398 can be moved to a shallower depth. For example, the overburden portions of legs 534, 536 may be relatively close together while the heated portions of the legs diverge below the overburden to greater separation distances needed for desired heating the formation. In certain embodiments, as depicted in FIG. 100, legs 534, 536 are ungrounded with the casings lowered the selected distance.

[0900] When the electrically conductive portions of casings 564/398 are lowered to selected depth 576, ground loop 568 may become the location of the highest field gradient at the surface. In some embodiments, a ground wellbore may be located below the surface and coupled to ground loop 568 (for example, with an insulated conductor (cable)). Coupling ground loop 568 to the ground wellbore below the surface may substantially reduce the high field gradient at the surface. The ground wellbore may be at a depth specified, for example, by standard electrical grounding practices known in the art.

[0901] In some embodiments, a subsurface hydrocarbon containing formation may be treated by the in situ heat treatment process to produce mobilized and/or pyrolyzed products from the formation. In some embodiments, a subsurface heater may include two or more heat generating electrical conductors. The conductors may be, for example, flexible conductors and/or insulated conductors (such as mineral insulated conductors). The conductors may be positioned in a tubular. In some embodiments, the conductors are positioned between two tubulars. In certain embodiments, the conductors are positioned around an exterior surface of a first tubular. The conductors and the first tubular may be positioned in a second tubular. The first and second tubular may form a dual-walled wellbore liner. The conductors inside the first and second tubular allow the wellbore liner to be operated as a liner heater.

[0902] In some embodiments, the heater includes a plurality of conductors positioned between the first and second tubulars. In certain embodiments, the heater includes between 2 and 16, between 4 and 12, or between 6 and 9 conductors. In certain embodiments, the heater includes multiples of 3 conductors (for example, 3, 6, or 9 conductors). In some embodiments, the conductors are wound around the inner first tubular in a roughly spiral pattern (for example, a helical pattern). The conductors may be formed from single conductors (for example, single-phase conductors) or multiple conductors (for example, three-phase conductors). Installing the conductors in the spiral pattern may produce a more uniform temperature profile and/or relieve mechanical stresses on the conductors. The more uniform temperature profile may increase heater life. Spiraled conductors, positioned between two tubulars, may not have the same tendency to expand and contract apart, which may potentially cause eddy currents. Spiraled conductors positioned between two tubulars may be more easily coiled on a large reel for transport without the ends of the heaters becoming uneven in length.

[0903] In certain embodiments, the tubulars are coiled tubing tubulars. Integrating the conductors in the first and second tubulars may allow for installation using a coiled tubing spooler, straightener, and/or injector system (for example, a coiled tubing rig). For example, coiled tubing tubulars may be wound onto the tubing rig during or after construction of the heater and unwound from the tubing rig as the heater is installed into the subsurface formation. This type of installation method may not require additional time typically required to attach the heat generating conductor to a pipe wall during well installation, reducing the overall workover cost. The tubing rig may be readily transported from the construction site to the heater installation site using methods known in the art or described herein. Use of the dual walled coiled tubing heating system may allow for retrieval of the system during initial operations.

[0904] In some embodiments, at least a portion of the conductors are in contact with the outer second tubular. FIGS. 101 and 102 depict cross-sectional representations of heaters 412

including three single-phase conductors 380 positioned between first tubulars 578A and second tubulars 578B. FIG. 103 depicts a cross-sectional representation of heater 412 including nine single-phase conductors 380 positioned between first tubular 578A and second tubular 578B. Forming heater 412 such that conductors 380 are in contact with the second tubular 578B results in the conductors providing conductive heat transfer between the first tubular 578A and the second tubular (as shown in FIGS. 101, 102, and 103). In such embodiments, conductive heat transfer functions as the primary method of heat transfer to second tubular 578B.

[0905] In some embodiments, conductors 380 are inhibited from contacting the outer second tubular. FIG. 104 depicts a cross-sectional representation of heater 412 including nine single-phase conductors 380 positioned between first tubular 578A and second tubular 578B with spacers 580. Spacers 580 may be positioned between first tubular 578A and second tubular 578B. The spacers may function to maintain separation between the tubulars and inhibit conductors 380 from contacting second tubular 578B. In such embodiments, radiative heat transfer functions as the primary method of heat transfer to second tubular 578B.

[0906] In some embodiments, spacers 580 are formed from an insulating material. For example, spacers may be formed from a fibrous ceramic material such as Nextel™ 312 (3M Corporation, St. Paul, Minnesota, U.S.A.), mica tape, glass fiber, or combinations thereof. Ceramic material may be made of alumina, alumina-silicate, alumina-borosilicate, silicon nitride, boron nitride, other suitable high-temperature materials, or mixtures thereof.

[0907] In some embodiments, heat transfer material (for example, heat transfer fluid) is located in the annulus between first tubular 578A and second tubular 578B. Heat transfer material may increase the efficiency of the heaters. Heat transfer material includes, but is not limited to, molten metal, molten salt, other heat conducting liquids, or heat conducting gases.

[0908] Conductors 380 may include single cores or multiple cores. In some embodiments, the conductors used in the heater include single cores installed between the first and second tubulars (for example, cores 374 in conductors 380 depicted in FIGS. 101, 102, 103, and 104). The cores may be electrically connected as single phase cores or coupled together in groups of 3 in 3-phase configurations (for example, 3-phase wye configurations). The electrical connections may be completed by bonding two cores and up to nine or more cores together.

[0909] The single cores may be connected together (for example, bonded) at the un-powered end, creating a single phase heating system (two cores connected) and up to, for example, three, 3-phase heating systems (nine cores connected to three power sources). These connections may be located at the subterranean end of the heating system (for example, near the toe of a horizontal heater wellbore). At the powered connection of the heater, the single-phase cores may be connected to line-to-line voltage (for example, up to 4160 V) for heat generation. 3-phase

heaters may be connected electrically on the surface using a 3-phase power transformer. Line-to-neutral voltage for these heaters may be up to about 2402 V ($V/\sqrt{3}$) since they are electrically connected at the un-powered subterranean end.

[0910] In some embodiments, conductors 380 used in the heater include multiple cores 374 installed between the first and second tubulars. For example, conductors 380 may include three multiple cores 374 configured to be provided power by a 3-phase transformer. FIG. 105 depicts a cross-sectional representation of heater 412 including nine multiple conductors 380 (in FIG. 105, each conductor includes three cores 374) positioned between first tubular 578A and second tubular 578B. FIG. 106 depicts a cross-sectional representation of heater 412 including nine multiple conductors 380 (in FIG. 106, each conductor includes three cores 374) positioned between first tubular 578A and second tubular 578B with spacers 580. Heater 412, depicted in FIG. 106, includes spacers 580. The multiple core conductors depicted in FIGS. 105 and 106 may be coupled together at the un-powered end (for example, bonded at the un-powered end). These connections may be located at the subterranean end of the heating system (for example, near the toe of a horizontal heater wellbore). Connecting the cores at the un-powered end may create electrically independent, individual heating systems that are powered, up to nine or more at a time, to reduce the heat-up time constant for the desired formation temperature or three at a time to maintain the desired formation temperature. The line to neutral voltage for these heaters may be up to about 2402 V ($4160/ V/\sqrt{3}$) since they are connected at the un-powered subterranean end.

[0911] The liner heaters, depicted in FIGS. 103, 104, 105, and 106, may include built-in redundancy in either the single core or multiple core designs. By connecting the cores to a common node at the end of the heating system, the single core conductors may be powered to by-pass a non-working conductor, creating a 3-phase or single phase heating system.

[0912] In some embodiments, the first and/or second tubulars include two or more openings. The openings may allow fluids to be moved upwards and/or downwards through the tubulars. For example, formation fluids may be produced through one of the openings inside the tubulars. Having the openings inside the tubulars may promote heat transfer and/or hydrocarbon accumulation for production assistance (out-flow assurance) or formation heating (in-flow assurance). In some embodiments, the use of spacers enhances flow assurance inside the openings by reducing heat losses to the formation and increasing heat transfer to fluids flowing through the openings.

[0913] In some embodiments, the liner heater is installed in a wellbore. The heater may allow the heat generated to be primarily transferred by conduction, directly into the near wellbore interface. The heat generation system may be in intimate contact with the near wellbore interface

such that the operating temperatures of the heating system may be reduced. Reducing operating temperatures of the heater may extend the expected lifetime of the heater. Lower operating temperatures resulting from integrating the electro-thermal heating system within the dual wall coiled tubular liner may increase the reliability of all components such as: a) outer sheath material; b) ceramic insulation; c) conductor(s) material; d) splices; and e) components. Reducing operating temperatures of the heater may inhibit hydrocarbon coking.

[0914] Because the liner heater is located in the liner portion of the wellbore, the use of a heating system in the interior of the wellbore may be eliminated. Eliminating the need for a heating system in the interior of the wellbore may allow for unobstructed heated oil production through the wellbore. Eliminating the need for a heating system in the interior of the wellbore may allow for the ability to introduce heated diluents or process-inducing additives to the formation through the interior of the wellbore.

[0915] FIG. 107 depicts representation of an embodiment of liner heater 412 in substantially horizontal wellbore 490 used for producing hydrocarbons from hydrocarbon layer 388. In certain embodiments, hydrocarbon layer 388 is a tar sands or other heavy hydrocarbon containing formation. Wellbore 490 has one or more openings to allow fluids (for example, mobilized and/or pyrolyzed hydrocarbons) to flow into the wellbore from hydrocarbon layer 388 (as shown by arrows on perimeter of the wellbore). Fluids in wellbore 490 are produced to the surface of the formation through the center annulus of heater 412 (as shown by the arrows in the center of the heater). Thus, the center annulus of heater 412 is used as a production conduit.

[0916] In certain embodiments, heater 412 only allows fluids to enter the center of the heater at the distal end of the heater (the end furthest from the surface or the "toe" of the heater). Thus, fluids that enter wellbore 490 must flow to the toe of heater 412 before entering the production conduit in the center of the heater. Fluids inside of heater 412 may flow back to the proximal horizontal end of the heater (the horizontal end closest to the surface of the "heel" of the heater). At the heel of heater 412, the fluids may be gas lifted or otherwise produced to the surface using known techniques. Heater 412 may include apparatus and mechanisms 1344 for gas lifting or pumping produced oil to the surface. Apparatus and mechanisms 1344 may includes gas lift valves used in a gas lift process. Examples of gas lift control systems and valves are disclosed in U.S. Patent Nos. 6,715,550 to Vinegar et al. and 7,259,688 to Hirsch et al., and U.S. Patent Application Publication No. 2002-0036085 to Bass et al. Forcing fluids to flow to the toe of heater 412 in wellbore 490 on the outside of the heater and back to the heel of the heater on the inside of the heater in the horizontal portion of the wellbore creates a substantially uniform temperature profile along the length of the heater. For example, the temperature profile is more

uniform than if fluids are allowed into the heater at any point or several points along the length of the heater.

[0917] In some embodiments, heater 412 includes two or more portions that function to heat at different power levels and, thus, heat at different temperatures. For example, higher power levels and higher temperatures may be generated in portions adjacent the hydrocarbon containing layer. Lower power levels (for example, <5% of the higher power level) and lower temperatures may be generated in portions adjacent the overburden. In some embodiments, lower power level conductors are designed and made utilizing larger diameter and/or different alloys with lower volume resistivities and low-power-producing conductors as compared with the high power level conductors. In some embodiments, the power reduction in the overburden is accomplished by using a conductor with a Curie-temperature power-limiting inherent characteristic (for example, low temperature and/or temperature limiting characteristics).

[0918] In certain embodiments, as shown in FIG. 107, conductor 380 of heater 412 includes lead-in section 1340 near the heel of the heater. Lead-in section 1340 couples conductor 380 to lead-in cable 540 at connector 1004. In certain embodiments, lead-in section 1340 is a section of conductor 380 that provides less heat (is cooler) than the remainder of the heater. In some embodiments, lead-in section 1340 has a length that allows for conductor 380 to reach temperatures suitable for conventional connection techniques to be used at connector 1004. For example, connector 1004 may be a conventional electrical splice available from Tyco International Inc. (Princeton, New Jersey, U.S.A.). In addition, a conventional lead-in cable 540 may be used to couple to conductor 380. An example of a conventional lead-in cable 540 is a pump cable such as that used for a submersible pump. Cores of conductor 380 may be coupled at the toe of heater 412 using a standard connector such as those available from Tyco International Inc.

[0919] In certain embodiments, lead-in section 1340 includes a copper core or other highly electrically conductive core that produces little or no heat. The copper core may be coupled to the remainder of the core that generates heat in the wellbore (for example, the remainder of the core may be alloy 180 or another suitable electrical conductor for heating in a production wellbore). In certain embodiments, the copper core is spliced to the remainder of the core. FIG. 108 depicts a cross-sectional representation of conductor 380 with core 374B of lead-in section 1340 spliced to core 374A of the remainder of the conductor. Splice 1342 couples core 374A to core 374B. Splice 1342 may be any type of splice known in the art for joining electrical conductors. In certain embodiments, core 374A, core 374B, and splice 1342 have substantially similar diameters.

[0920] In certain embodiments, portions of the wellbore that extend through the overburden include casings. The casings may include materials that inhibit inductive effects in the casings. Inhibiting inductive effects in the casings may inhibit induced currents in the casing and/or reduce heat losses to the overburden. In some embodiments, the overburden casings may include non-metallic materials such as fiberglass, polyvinylchloride (PVC), chlorinated PVC (CPVC), high-density polyethylene (HDPE), high temperature polymers (such as nitrogen based polymers), or other high temperature plastics. HDPEs with working temperatures in a usable range include HDPEs available from Dow Chemical Co., Inc. (Midland, Michigan, U.S.A.). The overburden casings may be made of materials that are spoolable so that the overburden casings can be spooled into the wellbore. In some embodiments, overburden casings may include non-magnetic metals such as aluminum or non-magnetic alloys such as manganese steels having at least 10% manganese, iron aluminum alloys with at least 18% aluminum, or austentitic stainless steels such as 304 stainless steel or 316 stainless steel. In some embodiments, overburden casings may include carbon steel or other ferromagnetic material coupled on the inside diameter to a highly conductive non-ferromagnetic metal (for example, copper or aluminum) to inhibit inductive effects or skin effects. In some embodiments, overburden casings are made of inexpensive materials that may be left in the formation (sacrificial casings).

[0921] In certain embodiments, wellheads for the wellbores may be made of one or more non-ferromagnetic materials. FIG. 109 depicts an embodiment of wellhead 392. The components in the wellheads may include fiberglass, PVC, CPVC, HDPE, high temperature polymers (such as nitrogen based polymers), and/or non-magnetic alloys or metals. Some materials (such as polymers) may be extruded into a mold or reaction injection molded (RIM) into the shape of the wellhead. Forming the wellhead from a mold may be a less expensive method of making the wellhead and save in capital costs for providing wellheads to a treatment site. Using non-ferromagnetic materials in the wellhead may inhibit undesired heating of components in the wellhead. Ferromagnetic materials used in the wellhead may be electrically and/or thermally insulated from other components of the wellhead. In some embodiments, an inert gas (for example, nitrogen or argon) is purged inside the wellhead and/or inside of casings to inhibit reflux of heated gases into the wellhead and/or the casings.

[0922] In some embodiments, ferromagnetic materials in the wellhead are electrically coupled to a non-ferromagnetic material (for example, copper) to inhibit skin effect heat generation in the ferromagnetic materials in the wellhead. The non-ferromagnetic material is in electrical contact with the ferromagnetic material so that current flows through the non-ferromagnetic material. In certain embodiments, as shown in FIG. 109, non-ferromagnetic material 582 is coupled (and electrically coupled) to the inside walls of conduit 382 and wellhead walls 584. In some

embodiments, copper may be plasma sprayed, coated, clad, or lined on the inside and/or outside walls of the wellhead. In some embodiments, a non-ferromagnetic material such as copper is welded, brazed, clad, or otherwise electrically coupled to the inside and/or outside walls of the wellhead. For example, copper may be swaged out to line the inside walls in the wellhead. Copper may be liquid nitrogen cooled and then allowed to expand to contact and swage against the inside walls of the wellhead. In some embodiments, the copper is hydraulically expanded or explosively bonded to contact against the inside walls of the wellhead.

[0923] In some embodiments, two or more substantially horizontal wellbores are branched off of a first substantially vertical wellbore drilled downwards from a first location on a surface of the formation. The substantially horizontal wellbores may be substantially parallel through a hydrocarbon layer. The substantially horizontal wellbores may reconnect at a second substantially vertical wellbore drilled downwards at a second location on the surface of the formation. Having multiple wellbores branching off of a single substantially vertical wellbore drilled downwards from the surface reduces the number of openings made at the surface of the formation.

[0924] Typical temperature measurement methods may be difficult and/or expensive to implement for use in assessing a temperature profile of a heater located in a subsurface formation for heating in an in situ heat treatment process. The desire is for a temperature profile that includes multiple temperatures along the length or a portion of the heater in the subsurface formation. Thermocouples are one possible solution; however, thermocouples provide only one temperature at one location and one wire is generally needed for each thermocouple. Thus, to obtain a temperature profile along a length of the heater, multiple wires are needed. The risk of failure of one or more of the thermocouples (or their associated wires) is increased with the use of multiple wires in the subsurface wellbore.

[0925] Another possible solution is the use of a fiber optic cable temperature sensor system. The fiber optic cable system provides a temperature profile along a length of the heater. Commercially available fiber optic cable systems, however, typically only have operating temperature ranges up to about 300 °C. Thus, these systems are not suitable for measurement of higher temperatures encountered while heating the subsurface formation during the in situ heat treatment process. Some experimental fiber optic cable systems are suitable for use at these higher temperatures but these systems may be too expensive for implementation in a commercial process (for example, a large field of heaters). Thus, there is a need for a simple, inexpensive system that allows temperature assessment at one or more locations along a length of the subsurface heater used in the in situ heat treatment process.

[0926] Current techniques allow for the measurement of dielectric properties of insulation along a length of the insulation (measurement of dielectric properties distributed along the length of the insulation). These techniques provide a profile of the dielectric properties with a spatial resolution (space between measurements) based on the type of insulation and the abilities of the measurement system. These techniques are currently used to assess dielectric properties and detect insulation flaws and/or insulation damage. Examples of current techniques are axial tomography and line resonance analysis. A version of axial tomography (Mashikian Axial Tomography) is provided by Instrument Manufacturing Company (IMCORP) (Storrs, Connecticut, U.S.A.). Mashikian Axial Tomography is disclosed in U.S. Pat. Application Pub. No. 2008-0048668 to Mashikian. A version of line resonance analysis (LIRA) is provided by Wirescan AS (Halden, Norway). Wirescan AS LIRA is disclosed in International Pat. Pub. No. WO 2007/040406 to Fantoni.

[0927] The assessment of dielectric properties (using either the current techniques or modified versions of these techniques) may be used in combination with information about the temperature dependence of dielectric properties to assess a temperature profile of one or more energized heaters (heaters that are powered and providing heat). The temperature dependence data of the dielectric properties may be found from simulation and/or experimentation. Examples of dielectric properties of the insulation that may be assessed over time include, but are not limited to, dielectric constant and loss tangent. FIG. 110 depicts an example of a plot of dielectric constant versus temperature for magnesium oxide insulation in one embodiment of an insulated conductor heater. FIG. 111 depicts an example of a plot of loss tangent (tan δ) versus temperature for magnesium oxide insulation in one embodiment of an insulated conductor heater.

[0928] It should be noted that the temperature dependent behavior of a dielectric property may vary based on certain factors. Factors that may affect the temperature dependent behavior of the dielectric property include, but are not limited to, the type of insulation, the dimensions of the insulation, the time the insulation is exposed to environment (for example, heat from the heater), the composition (chemistry) of the insulation, and the compaction of the insulation. Thus, it is typically necessary to measure (either by simulation and/or experimentation) the temperature dependent behavior of the dielectric property for the embodiment of insulation that is to be used in a selected heater.

[0929] In certain embodiments, one or more dielectric properties of the insulation in a heater having electrical insulation are assessed (measured) and compared to temperature dependence data of the dielectric properties to assess (determine) a temperature profile along a length of the heater (for example, the entire length of the heater or a portion of the heater). For example, the temperature of an insulated conductor heater (such as a mineral insulated (MI) cable heater) may

be assessed based on dielectric properties of the insulation used in the heater. Examples of insulated conductor heaters are depicted in FIGS. 29A, 29B, and 36. Since the temperature dependence of the dielectric property measured is known or estimated from simulation and/or experimentation, the measured dielectric property at a location along the heater may be used to assess the temperature of the heater at that location. Using techniques that measure the dielectric properties at multiple locations along a length of the heater (as is possible with current techniques), a temperature profile along that heater length may be provided.

[0930] In some embodiments, as shown by the plots in FIGS. 110 and 111, the dielectric properties are more sensitive to temperature at higher temperatures (for example, above about 900 °F, as shown in FIGS. 110 and 111). Thus, in some embodiments, the temperature of a portion of the insulated conductor heater is assessed by measurement of the dielectric properties at temperatures above about 400 °C (about 760 °F). For example, the temperature of the portion may be assessed by measurement of the dielectric properties at temperatures ranging from about 400 °C, about 450 °C, or about 500 °C to about 800 °C, about 850 °C, or about 900 °C. These ranges of temperatures are above temperatures that can be measured using commercially available fiber optic cable systems. A fiber optic cable system suitable for use in the higher temperature ranges may, however, provide measurements with higher spatial resolution than temperature assessment by measurement of the dielectric properties. Thus, in some embodiments, the fiber optic cable system operable in the higher temperature ranges may be used to calibrate temperature assessment by measurement of dielectric properties.

[0931] At temperatures below these temperature ranges (for example, below about 400 °C), temperature assessment by measurement of the dielectric properties may be less accurate. Temperature assessment by measurement of the dielectric properties may, however, provide a reasonable estimate or "average" temperature of portions of the heater. The average temperature assessment may be used to assess whether the heater is operating in a safe range. Typically, a heater operating at temperatures below about 400 °C, below about 450 °C, or below about 500 °C is operating in the safe range.

[0932] Temperature assessment by measurement of dielectric properties may provide a temperature profile along a length or portion of the insulated conductor heater (temperature measurements distributed along the length or portion of the heater). Measuring the temperature profile is more useful for monitoring and controlling the heater as compared to taking temperature measurements at only selected locations (such as temperature measurement with thermocouples). Multiple thermocouples may be used to provide a temperature profile. Multiple wires (one for each thermocouple), however, would be needed. Temperature assessment by measurement of dielectric properties uses only one wire for measurement of the temperature

profile, which is simpler and less expensive than using multiple thermocouples. In some embodiments, one or more thermocouples placed at selected locations are used to calibrate temperature assessment by measurement of dielectric properties.

[0933] In certain embodiments, the dielectric properties of the insulation in an insulated conductor heater are assessed (measured) over a period of time to assess the temperature and operating characteristics of the heater over the period of time. For example, the dielectric properties may be assessed continuously (or substantially continuously) to provide real-time monitoring of the dielectric properties and the temperature. Monitoring of the dielectric properties and the temperature may be used to assess the condition of the heater during operation of the heater. For example, comparison of the assessed properties at specific locations versus the average properties over the length of the heater may provide information on the location of hot spots or defects in the heater.

[0934] In some embodiments, the dielectric properties of the insulation change over time. For example, the dielectric properties may change over time because of changes in the oxygen concentration in the insulation over time and/or changes in the water content in the insulation over time. Oxygen in the insulation may be consumed by chromium or other metals used in the insulated conductor heater. Thus, the oxygen concentration decreases with time in the insulation and affects the dielectric properties of the insulation.

[0935] The changes in dielectric properties over time may be measured and compensated for through experimental and/or simulated data. For example, the insulated conductor heater to be used for temperature assessment may be heated in an oven or other apparatus and the changes in dielectric properties can be measured over time at various temperatures and/or at constant temperatures. In addition, thermocouples may be used to calibrate the assessment of dielectric properties changes over time by comparison of thermocouple data to temperature assessed by the dielectric properties.

[0936] In certain embodiments, temperature assessment by measurement of dielectric properties is performed using a computational system such as a workstation or computer. The computational system may receive measurements (assessments) of the dielectric properties along the heater and correlate these measured dielectric properties to assess temperatures at one or more locations on the heater. For example, the computational system may store data about the relationship of the dielectric properties to temperature (such as the data depicted in FIGS. 110 and 111) and/or time, and use this stored data to calculate the temperatures on the heater based on the measured dielectric properties.

[0937] In certain embodiments, temperature assessment by dielectric properties measurement is performed on an energized heater providing heat to the subsurface formation (for example, an

insulated conductor heater provided with electric power to resistively heat and provide heat to the subsurface formation). Assessing temperature on the energized heater allows for detection of defects in the insulation on the device actually providing heat to the formation. Assessing temperature on the energized heater, however, may be more difficult due to attenuation of signal along the heater because the heater is resistively heating. This attenuation may inhibit seeing further along the length of the heater (deeper into the formation along the heater). In some embodiments, temperatures in the upper sections of heaters (sections of the heater closer to the overburden, for example, the upper half or upper third of the heater) may be more important for assessment because these sections have higher voltages applied to the heater, are at higher temperatures, and are at higher risk for failure or generation of hot spots. The signal attenuation in the temperature assessment by dielectric properties measurement may not be as significant a factor in these upper sections because of the proximity of these sections to the surface.

[0938] In some embodiments, power to the insulated conductor heater is turned off before performing the temperature assessment. Power is then returned to the insulated conductor heater after the temperature assessment. Thus, the insulated conductor heater is subjected to a heating on/off cycle to assess temperature. This on/off cycle may, however, reduce the lifetime of the heater due to the thermal cycling. In addition, the heater may cool off during the non-energized time period and provide less accurate temperature information (less accurate information on the actual working temperature of the heater).

[0939] In certain embodiments, temperature assessment by dielectric properties measurement is performed on an insulated conductor that is not to be used for heating or not configured for heating. Such an insulated conductor may be a separate insulated conductor temperature probe. In some embodiments, the insulated conductor temperature probe is a non-energized heater (for example, an insulated conductor heater not powered). The insulated conductor temperature probe may be a stand-alone device that can be located in an opening in the subsurface formation to measure temperature in the opening. In some embodiments, the insulated conductor temperature probe is a looped probe that goes out and back into the opening with signals transmitted in one direction on the probe. In some embodiments, the insulated conductor temperature probe is a single hanging probe with the signal transmitted along the core and returned along the sheath of the insulated conductor.

[0940] In certain embodiments, the insulated conductor temperature probe includes a copper core (to provide better conductance to the end of the cable and better spatial resolution) surrounded by magnesium oxide insulation and an outer metal sheath. The outer metal sheath may be made of any material suitable for use in the subsurface opening. For example, the outer metal sheath may be a stainless steel sheath or an inner sheath of copper wrapped with an outer sheath of stainless

steel. Typically, the insulated conductor temperature probe operates up to temperatures and pressures that can be withstood by the outer metal sheath.

[0941] In some embodiments, the insulated conductor temperature probe is located adjacent to or near an energized heater in the opening to measure temperatures along the energized heater. There may be a temperature difference between the insulated conductor temperature probe and the energized heater (for example, between about 50 °C and 100 ° C temperature differences). This temperature difference may be assessed through experimentation and/or simulation and accounted for in the temperature measurements. The temperature difference may also be calibrated using one or more thermocouples attached to the energized heater.

[0942] In some embodiments, one or more thermocouples are attached to the insulated conductor used for temperature assessment (either an energized insulated conductor heater or a non-energized insulated conductor temperature probe). The attached thermocouples may be used for calibration and/or backup measurement of the temperature assessed on the insulated conductor by dielectric property measurement. In some embodiments, calibration and/or backup temperature indication is achieved by assessment of the resistance variation of the core of the insulated conductor at a given applied voltage. Temperature may be assessed by knowing the resistance versus temperature profile of the core material at the given voltage. In some embodiments, the insulated conductor is a loop and current induced in the loop from energized heaters in the subsurface opening provides input for the resistance measurement.

[0943] In certain embodiments, insulation material properties in the insulated conductor are varied to provide different sensitivities to temperature for the insulated conductor. Examples of insulation material properties that may be varied include, but are not limited to, the chemical and phase composition, the microstructure, and/or the mixture of insulating materials. Varying the insulation material properties in the insulated conductor allows the insulated conductor to be tuned to a selected temperature range. The selected temperature range may be selected, for example, for a desired application of the insulated conductor.

[0944] In some embodiments, insulation material properties are varied along the length of the insulated conductor (the insulation material properties are different at selected points within the insulated conductor). Varying properties of the insulation material at known locations along the length of the insulated conductor allows the measurement of the dielectric properties to give location information and/or provide for self-calibration of the insulated conductor in addition to providing temperature assessment. In some embodiments, the insulated conductor includes a portion with insulation material properties that allow the portion to act as a reflector. The reflector portion may be used to limit temperature assessment to specific portions of the insulated

conductor (for example, a specific length of insulated conductor). One or more reflector portions may be used to provide spatial markers along the length of the insulated conductor.

[0945] Varying the insulation material properties adjusts the activation energy of the insulation material. Typically, increasing the activation energy of the insulation material reduces attenuation in the insulation material and provides better spatial resolution. Lowering the activation energy typically provides better temperature sensitivity. The activation energy may be raised or lowered, for example, by adding different components to the insulation material. For example, adding certain components to magnesium oxide insulation will lower the activation energy. Examples of components that may be added to magnesium oxide to lower the activation energy include, but are not limited to, titanium oxide, nickel oxide, and iron oxide.

[0946] In some embodiments, temperature is assessed using two or more insulated conductors. The insulated conductors may have different activation energies to provide a variation in spatial resolution and temperature sensitivity to more accurately assess temperature in the subsurface opening. The higher activation energy insulated conductor may be used to provide better spatial resolution and identify the location of hot spots or other temperature variations more accurately while the lower activation energy insulated conductor may be used to provide more accurate temperature measurement at those locations.

[0947] In some embodiments, temperature is assessed by assessing leakage current from the insulated conductor. Temperature dependence data of the leakage current may be used to assess the temperature based on assessed (measured) leakage current from the insulated conductor. The measured leakage current may be used in combination with information about the temperature dependence of the leakage current to assess a temperature profile of one or more heaters or insulated conductors located in a subsurface opening. The temperature dependence data of the leakage current may be found from simulation and/or experimentation. In certain embodiments, the temperature dependence data of the leakage current is also dependent on the voltage applied to the heater.

[0948] FIG. 112 depicts an example of a plot of leakage current (mA) versus temperature (°F) for magnesium oxide insulation in one embodiment of an insulated conductor heater at different applied voltages. Plot 586 is for an applied voltage of 4300 V. Plot 588 is for an applied voltage of 3600 V. Plot 590 is for an applied voltage of 2800 V. Plot 592 is for an applied voltage of 2100 V.

[0949] As shown by the plots in FIG. 112, the leakage current is more sensitive to temperature at higher temperatures (for example, above about 950 °F, as shown in FIG. 112). Thus, in some embodiments, the temperature of a portion of the insulated conductor heater is assessed by measurement of the leakage current at temperatures above about 500 °C (about 932 °F).

[0950] A temperature profile along a length of the heater may be obtained by measuring the leakage current along the length of the heater using techniques known in the art. In some embodiments, assessment of temperature by measuring the leakage current is used in combination with temperature assessment by dielectric properties measurement. For example, temperature assessment by measurement of the leakage current may be used to calibrate and/or backup temperature assessments made by measurement of dielectric properties.

[0951] In certain embodiments, an insulated conductor using salt as the electrical insulator is used for temperature measurement. The salt becomes an electrical conductor above the melting temperature (T_m) of the salt and allows current to flow through the electrical insulator. FIG. 113 depicts an embodiment of insulated conductor 410 with salt used as electrical insulator 364. Core 374 is copper or another suitable electrical conductor. Jacket 370 is stainless steel or another suitable corrosion-resistant electrical conductor. In one embodiment, core 374 is 0.125" (about 0.3175 cm) diameter copper surrounded by electrical insulator 364. Electrical insulator 364 is 0.1" (about 0.25 cm) thick salt insulation surrounded by jacket 370. Jacket 370 is 0.1" (about 0.25 cm) thick stainless steel. The outer diameter of insulated conductor 410 is then 0.525" (about 1.33 cm).

[0952] In certain embodiments, electrical insulator 364 includes a salt with a melting temperature (T_m) at a desired temperature. The desired temperature may be a temperature in the range of operation of a subsurface heater or a maximum temperature desired in the opening. For example, the desired temperature may be above about 300 °C or in a range between 300 °C, 400 °C, about 450 °C, or about 500 °C and about 800 °C, about 850 °C, or about 900 °C. Examples of salts include, but are not limited to, Na_2CO_3 (T_m = 851 °C), Li_2CO_3 (T_m = 732 °C), LiCl (T_m = 605 °C), KOH (T_m = 420 °C), KNO_3 (T_m = 334 °C), $NaNO_3$ (T_m = 308 °C), and mixtures thereof. In some embodiments, magnesium oxide (such as porous magnesium oxide) is added to the salt to provide mechanical centering support. The magnesium oxide maintains the integrity and structure of insulated conductor 410 when the salt melts. Porous magnesium oxide allows for electrical connectivity between core 374 and jacket 370 by having the salt distributed in the pores of the magnesium oxide.

[0953] In certain embodiments, a mixture of two or more salts is used in electrical insulator 364 of insulated conductor 410. Varying the composition of the salts in the mixture allows for adjusting and tuning the melting temperature of the mixture to a desired temperature. In some embodiments, the composition of eutectic mixtures of salts is adjusted and tuned to the desired temperature. Eutectic mixtures may allow for finer adjustment and tuning to the desired temperature. Examples of eutectic mixtures that may be used include, but are not limited to, K_2CO_3:Na_2CO_3:Li_2CO_3 and KNO_3:$NaNO_3$.

[0954] Insulated conductor 410 may be coupled to or located near one or more heaters in a subsurface wellbore to assess the temperature at one or more locations along the length of the insulated conductor at or near the heaters. In some embodiments, insulated conductor 410 is similar in length to the heaters in the subsurface wellbore. In some embodiments, insulated conductor 410 has a shorter length than the heaters. In some embodiments, more than one insulated conductor 410 may be used in the wellbore to assess the temperature at different locations in the wellbore and/or at different temperatures.

[0955] FIG. 114 depicts an embodiment of insulated conductor 410 located proximate heaters 412 in wellbore 490. In some embodiments, insulated conductor 410 is coupled to one or more of heaters 412. For example, insulated conductor 410 may be strapped to the assembly of heaters 412. Heaters 412 may be insulated conductor heaters, conductor-in-conduit heaters, other types of heaters described herein, or combinations thereof.

[0956] To assess a location that is hotter than other portions of insulated conductor 410, voltage is applied to core 374 and jacket 370 of the insulated conductor, as shown in FIG. 115. Below the melting temperature (T_m) of the salt, there is little or no current drawn by core 374 and jacket 370 because the salt is in a solid phase. In the solid phase, the salt acts as an electrical insulator with resistivities above about 10^6 Ω-cm.

[0957] In some embodiments, hot spot 594 may develop at some location along the insulated conductor 410. Hot spot 594 is hotter than other portions along the length of insulated conductor 410. Hot spot 594 may be caused by a hot spot developing on or near one or more heaters located in the wellbore (for example, heaters 412 depicted in FIG. 114). At hot spot 594, the salt melts and becomes a liquid or molten salt. In the liquid phase, the salt becomes an electrical conductor with resistivities below 1 Ω-cm. Thus, current begins to flow between the surface and hot spot 594, as shown by the arrows in FIG. 115. Once current begins to flow through core 374 and jacket 370 of insulated conductor 410, if the resistance of the core and the jacket are known, the distance from the surface to hot spot 594 (x in FIG. 115) may be assessed by the measured current at the surface.

[0958] In certain embodiments, multiple hotspots may be located using insulated conductor 410. Time domain reflectometry may be used to locate multiple hotspots along insulated conductor 410 because the insulated conductor has a coaxial geometry. FIG. 116 shows insulated conductor 410 with multiple hot spots 594A, 594B. Incident pulse 596 is provided to insulated conductor 410. Reflected pulses 598A, 594B are generated at corresponding hot spots 594A, 594B.

[0959] The conductive molten salt at hot spots 594A, 594B provides a strong impedance mismatch for the reflections. The reflection coefficient for each hotspot can be assessed using EQN. 8:

(EQN. 8) $\rho = (Z_{HS}-Z_0)/(Z_{HS}+Z_0)$;

[0960] where Z_{HS} is the impedance of the hotspot, and Z_0 is the impedance of the insulated conductor (cable).

[0961] The location of the hotspots (X_{HSa}, X_{HSb}) can be assessed by assessing (measuring) the transit time, τ, between the incident and reflected pulses and using EQN. 9:

(EQN. 9) $X_{HS} = v^* \tau/2$;

[0962] where $v = v_c/\sqrt{(\varepsilon)}$ is the propagation velocity, v_c, is the speed of light, and ε is the dielectric constant of the salt insulation, which depends upon the salt used and compaction of the insulated conductor. In some embodiments, a hairpin insulated conductor configuration is used. The hairpin configuration allows for testing from both ends of the insulated conductor and increases the accuracy of hotspot location.

[0963] In some embodiments, assessment of the locations of hotspots by assessing the current or pulses applied to salt based insulated conductor 410 is used in combination with temperature assessment using thermocouples and/or fiber optic cable temperature sensor. The thermocouples and/or fiber optic cable temperature sensor may be used for calibration and/or backup measurement of the temperature assessment using the salt based insulated conductor.

[0964] In certain embodiments, a temperature limited heater is utilized for heavy oil applications (for example, treatment of relatively permeable formations or tar sands formations). A temperature limited heater may provide a relatively low Curie temperature and/or phase transformation temperature range so that a maximum average operating temperature of the heater is less than 350 °C, 300 °C, 250 °C, 225 °C, 200 °C, or 150 °C. In an embodiment (for example, for a tar sands formation), a maximum temperature of the temperature limited heater is less than about 250 °C to inhibit olefin generation and production of other cracked products. In some embodiments, a maximum temperature of the temperature limited heater is above about 250 °C to produce lighter hydrocarbon products. In some embodiments, the maximum temperature of the heater may be at or less than about 500 °C.

[0965] A heater may heat a volume of formation adjacent to a production wellbore (a near production wellbore region) so that the temperature of fluid in the production wellbore and in the volume adjacent to the production wellbore is less than the temperature that causes degradation of the fluid. The heat source may be located in the production wellbore or near the production wellbore. In some embodiments, the heat source is a temperature limited heater. In some embodiments, two or more heat sources may supply heat to the volume. Heat from the heat

source may reduce the viscosity of crude oil in or near the production wellbore. In some embodiments, heat from the heat source mobilizes fluids in or near the production wellbore and/or enhances the flow of fluids to the production wellbore. In some embodiments, reducing the viscosity of crude oil allows or enhances gas lifting of heavy oil (at most about 10° API gravity oil) or intermediate gravity oil (approximately 12° to 20° API gravity oil) from the production wellbore. In certain embodiments, the initial API gravity of oil in the formation is at most 10°, at most 20°, at most 25°, or at most 30°. In certain embodiments, the viscosity of oil in the formation is at least 0.05 Pa·s (50 cp). In some embodiments, the viscosity of oil in the formation is at least 0.10 Pa·s (100 cp), at least 0.15 Pa·s (150 cp), or at least at least 0.20 Pa·s (200 cp). Large amounts of natural gas may have to be utilized to provide gas lift of oil with viscosities above 0.05 Pa·s. Reducing the viscosity of oil at or near the production wellbore in the formation to a viscosity of 0.05 Pa·s (50 cp), 0.03 Pa·s (30 cp), 0.02 Pa·s (20 cp), 0.01 Pa·s (10 cp), or less (down to 0.001 Pa·s (1 cp) or lower) lowers the amount of natural gas or other fluid needed to lift oil from the formation. In some embodiments, reduced viscosity oil is produced by other methods such as pumping.

[0966] The rate of production of oil from the formation may be increased by raising the temperature at or near a production wellbore to reduce the viscosity of the oil in the formation in and adjacent to the production wellbore. In certain embodiments, the rate of production of oil from the formation is increased by 2 times, 3 times, 4 times, or greater over standard cold production with no external heating of formation during production. Certain formations may be more economically viable for enhanced oil production using the heating of the near production wellbore region. Formations that have a cold production rate approximately between 0.05 m^3/(day per meter of wellbore length) and 0.20 m^3/(day per meter of wellbore length) may have significant improvements in production rate using heating to reduce the viscosity in the near production wellbore region. In some formations, production wells up to 775 m, up to 1000 m, or up to 1500 m in length are used. Thus, a significant increase in production is achievable in some formations. Heating the near production wellbore region may be used in formations where the cold production rate is not between 0.05 m^3/(day per meter of wellbore length) and 0.20 m^3/(day per meter of wellbore length), but heating such formations may not be as economically favorable. Higher cold production rates may not be significantly increased by heating the near wellbore region, while lower production rates may not be increased to an economically useful value.

[0967] Using the temperature limited heater to reduce the viscosity of oil at or near the production well inhibits problems associated with non-temperature limited heaters and heating the oil in the formation due to hot spots. One possible problem is that non-temperature limited heaters can cause coking of oil at or near the production well if the heater overheats the oil

because the heaters are at too high a temperature. Higher temperatures in the production well may also cause brine to boil in the well, which may lead to scale formation in the well. Non-temperature limited heaters that reach higher temperatures may also cause damage to other wellbore components (for example, screens used for sand control, pumps, or valves). Hot spots may be caused by portions of the formation expanding against or collapsing on the heater. In some embodiments, the heater (either the temperature limited heater or another type of non-temperature limited heater) has sections that are lower because of sagging over long heater distances. These lower sections may sit in heavy oil or bitumen that collects in lower portions of the wellbore. At these lower sections, the heater may develop hot spots due to coking of the heavy oil or bitumen. A standard non-temperature limited heater may overheat at these hot spots, thus producing a non-uniform amount of heat along the length of the heater. Using the temperature limited heater may inhibit overheating of the heater at hot spots or lower sections and provide more uniform heating along the length of the wellbore.

[0968] In certain embodiments, fluids in the relatively permeable formation containing heavy hydrocarbons are produced with little or no pyrolyzation of hydrocarbons in the formation. In certain embodiments, the relatively permeable formation containing heavy hydrocarbons is a tar sands formation. For example, the formation may be a tar sands formation such as the Athabasca tar sands formation in Alberta, Canada or a carbonate formation such as the Grosmont carbonate formation in Alberta, Canada. The fluids produced from the formation are mobilized fluids. Producing mobilized fluids may be more economical than producing pyrolyzed fluids from the tar sands formation. Producing mobilized fluids may also increase the total amount of hydrocarbons produced from the tar sands formation.

[0969] FIGS. 117-120 depict side view representations of embodiments for producing mobilized fluids from tar sands formations. In FIGS. 117-120, heaters 412 have substantially horizontal heating sections in hydrocarbon layer 388 (as shown, the heaters have heating sections that go into and out of the page). Hydrocarbon layer 388 may be below overburden 400. FIG. 117 depicts a side view representation of an embodiment for producing mobilized fluids from a tar sands formation with a relatively thin hydrocarbon layer. FIG. 118 depicts a side view representation of an embodiment for producing mobilized fluids from a hydrocarbon layer that is thicker than the hydrocarbon layer depicted in FIG. 117. FIG. 119 depicts a side view representation of an embodiment for producing mobilized fluids from a hydrocarbon layer that is thicker than the hydrocarbon layer depicted in FIG. 118. FIG. 120 depicts a side view representation of an embodiment for producing mobilized fluids from a tar sands formation with a hydrocarbon layer that has a shale break.

[0970] In FIG. 117, heaters 412 are placed in an alternating triangular pattern in hydrocarbon layer 388. In FIGS. 118, 119, and 120, heaters 412 are placed in an alternating triangular pattern in hydrocarbon layer 388 that repeats vertically to encompass a majority or all of the hydrocarbon layer. In FIG. 120, the alternating triangular pattern of heaters 412 in hydrocarbon layer 388 repeats uninterrupted across shale break 600. In FIGS. 117-120, heaters 412 may be equidistantly spaced from each other. In the embodiments depicted in FIGS. 117-120, the number of vertical rows of heaters 412 depends on factors such as, but not limited to, the desired spacing between the heaters, the thickness of hydrocarbon layer 388, and/or the number and location of shale breaks 600. In some embodiments, heaters 412 are arranged in other patterns. For example, heaters 412 may be arranged in patterns such as, but not limited to, hexagonal patterns, square patterns, or rectangular patterns.

[0971] In the embodiments depicted in FIGS. 117-120, heaters 412 provide heat that mobilizes hydrocarbons (reduces the viscosity of the hydrocarbons) in hydrocarbon layer 388. In certain embodiments, heaters 412 provide heat that reduces the viscosity of the hydrocarbons in hydrocarbon layer 388 below about 0.50 Pa·s (500 cp), below about 0.10 Pa·s (100 cp), or below about 0.05 Pa·s (50 cp). The spacing between heaters 412 and/or the heat output of the heaters may be designed and/or controlled to reduce the viscosity of the hydrocarbons in hydrocarbon layer 388 to desirable values. Heat provided by heaters 412 may be controlled so that little or no pyrolyzation occurs in hydrocarbon layer 388. Superposition of heat between the heaters may create one or more drainage paths (for example, paths for flow of fluids) between the heaters. In certain embodiments, production wells 206A and/or production wells 206B are located proximate heaters 412 so that heat from the heaters superimposes over the production wells. The superimposition of heat from heaters 412 over production wells 206A and/or production wells 206B creates one or more drainage paths from the heaters to the production wells. In certain embodiments, one or more of the drainage paths converge. For example, the drainage paths may converge at or near a bottommost heater and/or the drainage paths may converge at or near production wells 206A and/or production wells 206B. Fluids mobilized in hydrocarbon layer 388 tend to flow towards the bottommost heaters 412, production wells 206A and/or production wells 206B in the hydrocarbon layer because of gravity and the heat and pressure gradients established by the heaters and/or the production wells. The drainage paths and/or the converged drainage paths allow production wells 206A and/or production wells 206B to collect mobilized fluids in hydrocarbon layer 388.

[0972] In certain embodiments, hydrocarbon layer 388 has sufficient permeability to allow mobilized fluids to drain to production wells 206A and/or production wells 206B. For example, hydrocarbon layer 388 may have a permeability of at least about 0.1 darcy, at least about 1 darcy,

at least about 10 darcy, or at least about 100 darcy. In some embodiments, hydrocarbon layer 388 has a relatively large vertical permeability to horizontal permeability ratio (K_v/K_h). For example, hydrocarbon layer 388 may have a K_v/K_h ratio between about 0.01 and about 2, between about 0.1 and about 1, or between about 0.3 and about 0.7.

[0973] In certain embodiments, fluids are produced through production wells 206A located near heaters 412 in the lower portion of hydrocarbon layer 388. In some embodiments, fluids are produced through production wells 206B located below and approximately midway between heaters 412 in the lower portion of hydrocarbon layer 388. At least a portion of production wells 206A and/or production wells 206B may be oriented substantially horizontal in hydrocarbon layer 388 (as shown in FIGS. 117-120, the production wells have horizontal portions that go into and out of the page). Production wells 206A and/or 206B may be located proximate lower portion heaters 412 or the bottommost heaters.

[0974] In some embodiments, production wells 206A are positioned substantially vertically below the bottommost heaters in hydrocarbon layer 388. Production wells 206A may be located below heaters 412 at the bottom vertex of a pattern of the heaters (for example, at the bottom vertex of the triangular pattern of heaters depicted in FIGS. 117-120). Locating production wells 206A substantially vertically below the bottommost heaters may allow for efficient collection of mobilized fluids from hydrocarbon layer 388.

[0975] In certain embodiments, the bottommost heaters are located between about 2 m and about 10 m from the bottom of hydrocarbon layer 388, between about 4 m and about 8 m from the bottom of the hydrocarbon layer, or between about 5 m and about 7 m from the bottom of the hydrocarbon layer. In certain embodiments, production wells 206A and/or production wells 206B are located at a distance from the bottommost heaters 412 that allows heat from the heaters to superimpose over the production wells but at a distance from the heaters that inhibits coking at the production wells. Production wells 206A and/or production wells 206B may be located a distance from the nearest heater (for example, the bottommost heater) of at most ¾ of the spacing between heaters in the pattern of heaters (for example, the triangular pattern of heaters depicted in FIGS. 117-120). In some embodiments, production wells 206A and/or production wells 206B are located a distance from the nearest heater of at most ⅔, at most ½, or at most ⅓ of the spacing between heaters in the pattern of heaters. In certain embodiments, production wells 206A and/or production wells 206B are located between about 2 m and about 10 m from the bottommost heaters, between about 4 m and about 8 m from the bottommost heaters, or between about 5 m and about 7 m from the bottommost heaters. Production wells 206A and/or production wells 206B may be located between about 0.5 m and about 8 m from the bottom of hydrocarbon layer

388, between about 1 m and about 5 m from the bottom of the hydrocarbon layer, or between about 2 m and about 4 m from the bottom of the hydrocarbon layer.

[0976] In some embodiments, at least some production wells 206A are located substantially vertically below heaters 412 near shale break 600, as depicted in FIG. 120. Production wells 206A may be located between heaters 412 and shale break 600 to produce fluids that flow and collect above the shale break. Shale break 600 may be an impermeable barrier in hydrocarbon layer 388. In some embodiments, shale break 600 has a thickness between about 1 m and about 6 m, between about 2 m and about 5 m, or between about 3 m and about 4 m. Production wells 206A between heaters 412 and shale break 600 may produce fluids from the upper portion of hydrocarbon layer 388 (above the shale break) and production wells 206A below the bottommost heaters in the hydrocarbon layer may produce fluids from the lower portion of the hydrocarbon layer (below the shale break), as depicted in FIG. 120. In some embodiments, two or more shale breaks may exist in a hydrocarbon layer. In such an embodiment, production wells are placed at or near each of the shale breaks to produce fluids flowing and collecting above the shale breaks.

[0977] In some embodiments, shale break 600 breaks down (is desiccated or decomposes) as the shale break is heated by heaters 412 on either side of the shale break. As shale break 600 breaks down, the permeability of the shale break increases and fluids flow through the shale break. Once fluids are able to flow through shale break 600, production wells above the shale break may not be needed for production as fluids can flow to production wells at or near the bottom of hydrocarbon layer 388 and be produced there.

[0978] In certain embodiments, the bottommost heaters above shale break 600 are located between about 2 m and about 10 m from the shale break, between about 4 m and about 8 m from the bottom of the shale break, or between about 5 m and about 7 m from the shale break. Production wells 206A may be located between about 2 m and about 10 m from the bottommost heaters above shale break 600, between about 4 m and about 8 m from the bottommost heaters above the shale break, or between about 5 m and about 7 m from the bottommost heaters above the shale break. Production wells 206A may be located between about 0.5 m and about 8 m from shale break 600, between about 1 m and about 5 m from the shale break, or between about 2 m and about 4 m from the shale break.

[0979] In some embodiments, heat is provided in production wells 206A and/or production wells 206B, depicted in FIGS. 117-120. Providing heat in production wells 206A and/or production wells 206B may maintain and/or enhance the mobility of the fluids in the production wells. Heat provided in production wells 206A and/or production wells 206B may superimpose with heat from heaters 412 to create the flow path from the heaters to the production wells. In some embodiments, production wells 206A and/or production wells 206B include a pump to move

fluids to the surface of the formation. In some embodiments, the viscosity of fluids (oil) in production wells 206A and/or production wells 206B is lowered using heaters and/or diluent injection (for example, using a conduit in the production wells for injecting the diluent).

[0980] In certain embodiments, in situ heat treatment of the relatively permeable formation containing hydrocarbons (for example, the tar sands formation) includes heating the formation to visbreaking temperatures. For example, the formation may be heated to temperatures between about 100 °C and 260 °C, between about 150 °C and about 250 °C, between about 200 °C and about 240 °C, between about 205 °C and 230 °C, between about 210 °C and 225 °C. In one embodiment, the formation is heated to a temperature of about 220 °C. In one embodiment, the formation is heated to a temperature of about 230 °C. At visbreaking temperatures, fluids in the formation have a reduced viscosity (versus their initial viscosity at initial formation temperature) that allows fluids to flow in the formation. The reduced viscosity at visbreaking temperatures may be a permanent reduction in viscosity as the hydrocarbons go through a step change in viscosity at visbreaking temperatures (versus heating to mobilization temperatures, which may only temporarily reduce the viscosity). The visbroken fluids may have API gravities that are relatively low (for example, at most about 10°, about 12°, about 15°, or about 19° API gravity), but the API gravities are higher than the API gravity of non-visbroken fluid from the formation. The non-visbroken fluid from the formation may have an API gravity of 7° or less.

[0981] In some embodiments, heaters in the formation are operated at full power output to heat the formation to visbreaking temperatures or higher temperatures. Operating at full power may rapidly increase the pressure in the formation. In certain embodiments, fluids are produced from the formation to maintain a pressure in the formation below a selected pressure as the temperature of the formation increases. In some embodiments, the selected pressure is a fracture pressure of the formation. In certain embodiments, the selected pressure is between about 1000 kPa and about 15000 kPa, between about 2000 kPa and about 10000 kPa, or between about 2500 kPa and about 5000 kPa. In one embodiment, the selected pressure is about 10000 kPa. Maintaining the pressure as close to the fracture pressure as possible may minimize the number of production wells needed for producing fluids from the formation.

[0982] In certain embodiments, treating the formation includes maintaining the temperature at or near visbreaking temperatures (as described above) during the entire production phase while maintaining the pressure below the fracture pressure. The heat provided to the formation may be reduced or eliminated to maintain the temperature at or near visbreaking temperatures. Heating to visbreaking temperatures but maintaining the temperature below pyrolysis temperatures or near pyrolysis temperatures (for example, below about 230 °C) inhibits coke formation and/or higher level reactions. Heating to visbreaking temperatures at higher pressures (for example,

pressures near but below the fracture pressure) keeps produced gases in the liquid oil (hydrocarbons) in the formation and increases hydrogen reduction in the formation with higher hydrogen partial pressures. Heating the formation to only visbreaking temperatures also uses less energy input than heating the formation to pyrolysis temperatures.

[0983] Fluids produced from the formation may include visbroken fluids, mobilized fluids, and/or pyrolyzed fluids. In some embodiments, a produced mixture that includes these fluids is produced from the formation. The produced mixture may have assessable properties (for example, measurable properties). The produced mixture properties are determined by operating conditions in the formation being treated (for example, temperature and/or pressure in the formation). In certain embodiments, the operating conditions may be selected, varied, and/or maintained to produce desirable properties in hydrocarbons in the produced mixture. For example, the produced mixture may include hydrocarbons that have properties that allow the mixture to be easily transported (for example, sent through a pipeline without adding diluent or blending the mixture and/or resulting hydrocarbons with another fluid).

[0984] In some embodiments, after the formation reaches visbreaking temperatures, the pressure in the formation is reduced. In certain embodiments, the pressure in the formation is reduced at temperatures above visbreaking temperatures. Reducing the pressure at higher temperatures allows more of the hydrocarbons in the formation to be converted to higher quality hydrocarbons by visbreaking and/or pyrolysis. Allowing the formation to reach higher temperatures before pressure reduction, however, may increase the amount of carbon dioxide produced and/or the amount of coking in the formation. For example, in some formations, coking of bitumen (at pressures above 700 kPa) begins at about 280 °C and reaches a maximum rate at about 340 °C. At pressures below about 700 kPa, the coking rate in the formation is minimal. Allowing the formation to reach higher temperatures before pressure reduction may decrease the amount of hydrocarbons produced from the formation.

[0985] In certain embodiments, the temperature in the formation (for example, an average temperature of the formation) when the pressure in the formation is reduced is selected to balance one or more factors. The factors considered may include: the quality of hydrocarbons produced, the amount of hydrocarbons produced, the amount of carbon dioxide produced, the amount hydrogen sulfide produced, the degree of coking in the formation, and/or the amount of water produced. Experimental assessments using formation samples and/or simulated assessments based on the formation properties may be used to assess results of treating the formation using the in situ heat treatment process. These results may be used to determine a selected temperature, or temperature range, for when the pressure in the formation is to be reduced. The selected temperature, or temperature range, may also be affected by factors such as, but not limited to,

hydrocarbon or oil market conditions and other economic factors. In certain embodiments, the selected temperature is in a range between about 275 °C and about 305 °C, between about 280 °C and about 300 °C, or between about 285 °C and about 295 °C.

[0986] In certain embodiments, an average temperature in the formation is assessed from an analysis of fluids produced from the formation. For example, the average temperature of the formation may be assessed from an analysis of the fluids that have been produced to maintain the pressure in the formation below the fracture pressure of the formation.

[0987] In some embodiments, values of the hydrocarbon isomer shift in fluids (for example, gases) produced from the formation is used to indicate the average temperature in the formation. Experimental analysis and/or simulation may be used to assess one or more hydrocarbon isomer shifts and relate the values of the hydrocarbon isomer shifts to the average temperature in the formation. The assessed relation between the hydrocarbon isomer shifts and the average temperature may then be used in the field to assess the average temperature in the formation by monitoring one or more of the hydrocarbon isomer shifts in fluids produced from the formation. In some embodiments, the pressure in the formation is reduced when the monitored hydrocarbon isomer shift reaches a selected value. The selected value of the hydrocarbon isomer shift may be chosen based on the selected temperature, or temperature range, in the formation for reducing the pressure in the formation and the assessed relation between the hydrocarbon isomer shift and the average temperature. Examples of hydrocarbon isomer shifts that may be assessed include, but are not limited to, n-butane-$\delta^{13}C_4$ percentage versus propane- $\delta^{13}C_3$ percentage, n-pentane- $\delta^{13}C_5$ percentage versus propane- $\delta^{13}C_3$ percentage, n-pentane- $\delta^{13}C_5$ percentage versus n-butane- $\delta^{13}C_4$ percentage, and i-pentane- $\delta^{13}C_5$ percentage versus i-butane- $\delta^{13}C_4$ percentage. In some embodiments, the hydrocarbon isomer shift in produced fluids is used to indicate the amount of conversion (for example, amount of pyrolysis) that has taken place in the formation.

[0988] In some embodiments, weight percentages of saturates in fluids produced from the formation is used to indicate the average temperature in the formation. Experimental analysis and/or simulation may be used to assess the weight percentage of saturates as a function of the average temperature in the formation. For example, SARA (**S**aturates, **A**romatics, **R**esins, and **A**sphaltenes) analysis (sometimes referred to as Asphaltene/Wax/Hydrate Deposition analysis) may be used to assess the weight percentage of saturates in a sample of fluids from the formation. In some formations, the weight percentage of saturates has a linear relationship to the average temperature in the formation. The relation between the weight percentage of saturates and the average temperature may then be used in the field to assess the average temperature in the formation by monitoring the weight percentage of saturates in fluids produced from the formation. In some embodiments, the pressure in the formation is reduced when the monitored

weight percentage of saturates reaches a selected value. The selected value of the weight percentage of saturates may be chosen based on the selected temperature, or temperature range, in the formation for reducing the pressure in the formation and the relation between the weight percentage of saturates and the average temperature. In some embodiments, the selected value of weight percentage of saturates is between about 20% and about 40%, between about 25% and about 35%, or between about 28% and about 32%. For example, the selected value may be about 30% by weight saturates.

[0989] In some embodiments, weight percentages of n-C_7 in fluids produced from the formation is used to indicate the average temperature in the formation. Experimental analysis and/or simulation may be used to assess the weight percentages of n-C_7 as a function of the average temperature in the formation. In some formations, the weight percentages of n-C_7 has a linear relationship to the average temperature in the formation. The relation between the weight percentages of n-C_7 and the average temperature may then be used in the field to assess the average temperature in the formation by monitoring the weight percentages of n-C_7 in fluids produced from the formation. In some embodiments, the pressure in the formation is reduced when the monitored weight percentage of n-C_7 reaches a selected value. The selected value of the weight percentage of n-C_7 may be chosen based on the selected temperature, or temperature range, in the formation for reducing the pressure in the formation and the relation between the weight percentage of n-C_7 and the average temperature. In some embodiments, the selected value of weight percentage of n-C_7 is between about 50% and about 70%, between about 55% and about 65%, or between about 58% and about 62%. For example, the selected value may be about 60% by weight n-C_7.

[0990] The pressure in the formation may be reduced by producing fluids (for example, visbroken fluids and/or mobilized fluids) from the formation. In some embodiments, the pressure is reduced below a pressure at which fluids coke in the formation to inhibit coking at pyrolysis temperatures. For example, the pressure is reduced to a pressure below about 1000 kPa, below about 800 kPa, or below about 700 kPa (for example, about 690 kPa). In certain embodiments, the selected pressure is at least about 100 kPa, at least about 200 kPa, or at least about 300 kPa. The pressure may be reduced to inhibit coking of asphaltenes or other high molecular weight hydrocarbons in the formation. In some embodiments, the pressure may be maintained below a pressure at which water passes through a liquid phase at downhole (formation) temperatures to inhibit liquid water and dolomite reactions. After reducing the pressure in the formation, the temperature may be increased to pyrolysis temperatures to begin pyrolyzation and/or upgrading of fluids in the formation. The pyrolyzed and/or upgraded fluids may be produced from the formation.

[0991] In certain embodiments, the amount of fluids produced at temperatures below visbreaking temperatures, the amount of fluids produced at visbreaking temperatures, the amount of fluids produced before reducing the pressure in the formation, and/or the amount of upgraded or pyrolyzed fluids produced may be varied to control the quality and amount of fluids produced from the formation and the total recovery of hydrocarbons from the formation. For example, producing more fluid during the early stages of treatment (for example, producing fluids before reducing the pressure in the formation) may increase the total recovery of hydrocarbons from the formation while reducing the overall quality (lowering the overall API gravity) of fluid produced from the formation. The overall quality is reduced because more heavy hydrocarbons are produced by producing more fluids at the lower temperatures. Producing less fluids at the lower temperatures may increase the overall quality of the fluids produced from the formation but may lower the total recovery of hydrocarbons from the formation. The total recovery may be lower because more coking occurs in the formation when less fluids are produced at lower temperatures.

[0992] In certain embodiments, the formation is heated using isolated cells of heaters (cells or sections of the formation that are not interconnected for fluid flow). The isolated cells may be created by using larger heater spacings in the formation. For example, large heater spacings may be used in the embodiments depicted in FIGS. 117-120. These isolated cells may be produced during early stages of heating (for example, at temperatures below visbreaking temperatures). Because the cells are isolated from other cells in the formation, the pressures in the isolated cells are high and more liquids are producible from the isolated cells. Thus, more liquids may be produced from the formation and a higher total recovery of hydrocarbons may be reached. During later stages of heating, the heat gradient may interconnect the isolated cells and pressures in the formation will drop.

[0993] In certain embodiments, the heat gradient in the formation is modified so that a gas cap is created at or near an upper portion of the hydrocarbon layer. For example, the heat gradient made by heaters 412 depicted in the embodiments depicted in FIGS. 117-120 may be modified to create the gas cap at or near overburden 400 of hydrocarbon layer 388. The gas cap may push or drive liquids to the bottom of the hydrocarbon layer so that more liquids may be produced from the formation. In situ generation of the gas cap may be more efficient than introducing pressurized fluid into the formation. The in situ generated gas cap applies force evenly through the formation with little or no channeling or fingering that may reduce the effectiveness of introduced pressurized fluid.

[0994] In certain embodiments, the number and/or location of production wells in the formation is varied based on the viscosity of fluid in the formation. The viscosities in the zones may be

assessed before placing the production wells in the formation, before heating the formation, and/or after heating the formation. In some embodiments, more production wells are located in zones in the formation that have lower viscosities. For example, in certain formations, upper portions, or zones, of the formation may have lower viscosities. In some embodiments, more production wells are located in the upper zones. Producing through production wells in the less viscous zones of the formation may result in production of higher quality (more upgraded) oil from the formation.

[0995] In some embodiments, more production wells are located in zones in the formation that have higher viscosities. Pressure propagation may be slower in the zones with higher viscosities. The slower pressure propagation may make it more difficult to control pressure in the zones with higher viscosities. Thus, more production wells may be located in the zones with higher viscosities to provide better pressure control in these zones.

[0996] In some embodiments, zones in the formation with different assessed viscosities are heated at different rates. In certain embodiments, zones in the formation with higher viscosities are heated at higher heating rates than zones with lower viscosities. Heating the zones with higher viscosities at the higher heating rates mobilizes and/or upgrades these zones at a faster rate so that these zones may "catch up" in viscosity and/or quality to the slower heated zones.

[0997] In some embodiments, the heater spacing is varied to provide different heating rates to zones in the formation with different assessed viscosities. For example, denser heater spacings (less spaces between heaters) may be used in zones with higher viscosities to heat these zones at higher heating rates. In some embodiments, a production well (for example, a substantially vertical production well) is located in the zones with denser heater spacings and higher viscosities. The production well may be used to remove fluids from the formation and relieve pressure from the higher viscosity zones. In some embodiments, one or more substantially vertical openings, or production wells, are located in the higher viscosity zones to allow fluids to drain in the higher viscosity zones. The draining fluids may be produced from the formation through production wells located near the bottom of the higher viscosity zones.

[0998] In certain embodiments, production wells are located in more than one zone in the formation. The zones may have different initial permeabilities. In certain embodiments, a first zone has an initial permeability of at least about 1 darcy and a second zone has an initial permeability of at most about 0.1 darcy. In some embodiments, the first zone has an initial permeability of between about 1 darcy and about 10 darcy. In some embodiments, the second zone has an initial permeability between about 0.01 darcy and 0.1 darcy. The zones may be separated by a substantially impermeable barrier (with an initial permeability of about 10 μdarcy

or less). Having the production well located in both zones allows for fluid communication (permeability) between the zones and/or pressure equalization between the zones.

[0999] In some embodiments, openings (for example, substantially vertical openings) are formed between zones with different initial permeabilities that are separated by a substantially impermeable barrier. Bridging the zones with the openings allows for fluid communication (permeability) between the zones and/or pressure equalization between the zones. In some embodiments, openings in the formation (such as pressure relief openings and/or production wells) allow gases or low viscosity fluids to rise in the openings. As the gases or low viscosity fluids rise, the fluids may condense or increase viscosity in the openings so that the fluids drain back down the openings to be further upgraded in the formation. Thus, the openings may act as heat pipes by transferring heat from the lower portions to the upper portions where the fluids condense. The wellbores may be packed and sealed near or at the overburden to inhibit transport of formation fluid to the surface.

[1000] In some embodiments, production of fluids is continued after reducing and/or turning off heating of the formation. The formation may be heated for a selected time. The formation may be heated until it reaches a selected average temperature. Production from the formation may continue after the selected time. Continuing production may produce more fluid from the formation as fluids drain towards the bottom of the formation and/or as fluids are upgraded by passing by hot spots in the formation. In some embodiments, a horizontal production well is located at or near the bottom of the formation (or a zone of the formation) to produce fluids after heating is turned down and/or off.

[1001] In certain embodiments, initially produced fluids (for example, fluids produced below visbreaking temperatures), fluids produced at visbreaking temperatures, and/or other viscous fluids produced from the formation are blended with diluent to produce fluids with lower viscosities. In some embodiments, the diluent includes upgraded or pyrolyzed fluids produced from the formation. In some embodiments, the diluent includes upgraded or pyrolyzed fluids produced from another portion of the formation or another formation. In certain embodiments, the amount of fluids produced at temperatures below visbreaking temperatures and/or fluids produced at visbreaking temperatures that are blended with upgraded fluids from the formation is adjusted to create a fluid suitable for transportation and/or use in a refinery. The amount of blending may be adjusted so that the fluid has chemical and physical stability. Maintaining the chemical and physical stability of the fluid may allow the fluid to be transported, reduce pre-treatment processes at a refinery and/or reduce or eliminate the need for adjusting the refinery process to compensate for the fluid.

[1002] In certain embodiments, formation conditions (for example, pressure and temperature) and/or fluid production are controlled to produce fluids with selected properties. For example, formation conditions and/or fluid production may be controlled to produce fluids with a selected API gravity and/or a selected viscosity. The selected API gravity and/or selected viscosity may be produced by combining fluids produced at different formation conditions (for example, combining fluids produced at different temperatures during the treatment as described above). As an example, formation conditions and/or fluid production may be controlled to produce fluids with an API gravity of about 19° and a viscosity of about 0.35 Pa·s (350 cp) at 5 °C.

[1003] In certain embodiments, a drive process (for example, a steam injection process such as cyclic steam injection, a steam assisted gravity drainage process (SAGD), a solvent injection process, a vapor solvent and SAGD process, or a carbon dioxide injection process) is used to treat the tar sands formation in addition to the in situ heat treatment process. In some embodiments, heaters are used to create high permeability zones (or injection zones) in the formation for the drive process. Heaters may be used to create a mobilization geometry or production network in the formation to allow fluids to flow through the formation during the drive process. For example, heaters may be used to create drainage paths between the heaters and production wells for the drive process. In some embodiments, the heaters are used to provide heat during the drive process. The amount of heat provided by the heaters may be small compared to the heat input from the drive process (for example, the heat input from steam injection).

[1004] The concentration of components in the formation and/or produced fluids may change during an in situ heat treatment process. As the concentration of the components in the formation and/or produced fluids and/or hydrocarbons separated from the produced fluid changes due to formation of the components, solubility of the components in the produced fluids and/or separated hydrocarbons tends to change. Hydrocarbons separated from the produced fluid may be hydrocarbons that have been treated to remove salty water and/or gases from the produced fluid. For example, the produced fluids and/or separated hydrocarbons may contain components that are soluble in the condensable hydrocarbon portion of the produced fluids at the beginning of processing. As properties of the hydrocarbons in the produced fluids change (for example, TAN, asphaltenes, P-value, olefin content, mobilized fluids content, visbroken fluids content, pyrolyzed fluids content, or combinations thereof), the components may tend to become less soluble in the produced fluids and/or in the hydrocarbon stream separated from the produced fluids. In some instances, components in the produced fluids and/or components in the separated hydrocarbons may form two phases and/or become insoluble. Formation of two phases, through flocculation of asphaltenes, change in concentration of components in the produced fluids, change in

concentration of components in separated hydrocarbons, and/or precipitation of components may result in hydrocarbons that do not meet pipeline, transportation, and/or refining specifications. Additionally, the efficiency of the process may be reduced. For example, further treatment of the produced fluids and/or separated hydrocarbons may be necessary to produce products with desired properties.

[1005] During processing, the P-value of the separated hydrocarbons may be monitored and the stability of the produced fluids and/or separated hydrocarbons may be assessed. Typically, a P-value that is at most 1.0 indicates that flocculation of asphaltenes from the separated hydrocarbons generally occurs. If the P-value is initially at least 1.0, and such P-value increases or is relatively stable during heating, then this indicates that the separated hydrocarbons are relatively stable. Stability of separated hydrocarbons, as assessed by P-value, may be controlled by controlling operating conditions in the formation such as temperature, pressure, hydrogen uptake, hydrocarbon feed flow, or combinations thereof.

[1006] In some embodiments, change in API gravity may not occur unless the formation temperature is at least 100 °C. For some formations, temperatures of at least 220 °C may be required to produce hydrocarbons that meet desired specifications. At increased temperatures coke formation may occur, even at elevated pressures. As the properties of the formation are changed, the P-value of the separated hydrocarbons may decrease below 1.0 and/or sediment may form, causing the separated hydrocarbons to become unstable.

[1007] In some embodiments, olefins may form during heating of formation fluids to produce fluids having a reduced viscosity. Separated hydrocarbons that include olefins may be unacceptable for processing facilities. Olefins in the separated hydrocarbons may cause fouling and/or clogging of processing equipment. For example, separated hydrocarbons that contains olefins may cause coking of distillation units in a refinery, which results in frequent down time to remove the coked material from the distillation units.

[1008] During processing, the olefin content of separated hydrocarbons may be monitored and quality of the separated hydrocarbons assessed. Typically, separated hydrocarbons having a bromine number of 3% and/or a CAPP olefin number of 3% as 1-decene equivalent indicates that olefin production is occurring. If the olefin value decreases or is relatively stable during producing, then this indicates that a minimal or substantially low amount of olefins are being produced. Olefin content, as assessed by bromine value and/or CAPP olefin number, may be controlled by controlling operating conditions in the formation such as temperature, pressure, hydrogen uptake, hydrocarbon feed flow, or combinations thereof.

[1009] In some embodiments, the P-value and/or olefin content may be controlled by controlling operating conditions. For example, if the temperature increases above 225 °C and the P-value

drops below 1.0, the separated hydrocarbons may become unstable. Alternatively, the bromine number and/or CAPP olefin number may increase to above 3%. If the temperature is maintained below 225 °C, minimal changes to the hydrocarbon properties may occur. In certain embodiments, operating conditions are selected, varied, and/or maintained to produce separated hydrocarbons having a P-value of at least about 1, at least about 1.1, at least about 1.2, or at least about 1.3. In certain embodiments, operating conditions are selected, varied, and/or maintained to produce separated hydrocarbons having a bromine number of at most about 3%, at most about 2.5%, at most about 2%, or at most about 1.5%. Heating of the formation at controlled operating conditions includes operating at temperatures between about 100 °C and about 260 °C, between about 150 °C and about 250 °C, between about 200 °C and about 240 °C, between about 210 °C and about 230 °C, or between about 215 °C and about 225 °C. Pressures may be between about 1000 kPa and about 15000 kPa, between about 2000 kPa and about 10000 kPa, or between about 2500 kPa and about 5000 kPa or at or near a fracture pressure of the formation. In certain embodiments, the selected pressure of about 10000 kPa produces separated hydrocarbons having properties acceptable for transportation and/or refineries (for example, viscosity, P-value, API gravity, and/or olefin content within acceptable ranges).

[1010] Examples of produced mixture properties that may be measured and used to assess the separated hydrocarbon portion of the produced mixture include, but are not limited to, liquid hydrocarbon properties such as API gravity, viscosity, asphaltene stability (P-value), and olefin content (bromine number and/or CAPP number). In certain embodiments, operating conditions in the formation are selected, varied, and/or maintained to produce an API gravity of at least about 15°, at least about 17°, at least about 19°, or at least about 20° in the produced mixture. In certain embodiments, operating conditions in the formation are selected, varied, and/or maintained to produce a viscosity (measured at 1 atm and 5 °C) of at most about 400 cp, at most about 350 cp, at most about 250 cp, or at most about 100 cp in the produced mixture. As an example, the initial viscosity of fluid in the formation is above about 1000 cp or, in some cases, above about 1 million cp. In certain embodiments, operating conditions are selected, varied, and/or maintained to produce an asphaltene stability (P-value) of at least about 1, at least about 1.1, at least about 1.2, or at least about 1.3 in the produced mixture. In certain embodiments, operating conditions are selected, varied, and/or maintained to produce a bromine number of at most about 3%, at most about 2.5%, at most about 2%, or at most about 1.5% in the produced mixture.

[1011] In certain embodiments, the mixture is produced from one or more production wells located at or near the bottom of the hydrocarbon layer being treated. In other embodiments, the

mixture is produced from other locations in the hydrocarbon layer being treated (for example, from an upper portion of the layer or a middle portion of the layer).

[1012] In one embodiment, the formation is heated to 220 °C or 230 °C while maintaining the pressure in the formation below 10000 kPa. The separated hydrocarbon portion of the mixture produced from the formation may have several desirable properties such as, but not limited to, an API gravity of at least 19°, a viscosity of at most 350 cp, a P-value of at least 1.1, and a bromine number of at most 2%. Such separated hydrocarbons may be transportable through a pipeline without adding diluent or blending the mixture with another fluid. The mixture may be produced from one or more production wells located at or near the bottom of the hydrocarbon layer being treated.

[1013] In some embodiments, a hydrocarbon formation may be treated using an in situ heat treatment process based on assessment of the stability or product quality of the formation fluid produced from the formation. Asphaltenes may be produced through thermal cracking and condensation of hydrocarbons produced during a thermal conversion. The produced asphaltenes are a complex mixture of high molecular weight compounds containing polyaromatic rings and short side chains. The structure and/or aromaticity of the asphaltenes may affect the solubility of the asphaltenes in the produced formation fluids. During heating of the formation, at least a portion of the asphaltenes in the formation may react with other asphaltenes and form coke or higher molecular weight asphaltenes. Higher molecular weight asphaltenes may be less soluble in produced formation fluid that includes lower molecular weight compounds (for example, produced formation fluid that includes a significant amount of naphtha or kerosene). As formation fluids are converted to liquid hydrocarbons and the lower boiling hydrocarbons and/or gases are produced from the formation, the type of asphaltenes and/or solubility of the asphaltenes in the formation fluid may change. In conventional processing, as the formation is heated, the weight percent of asphaltenes and/or the H/C molar ratio of the asphaltenes may decrease relative to an initial weight percent of asphaltenes and/or the H/C molar ratio of the asphaltenes. In some instances, the asphaltene content may decrease due to the asphaltenes forming coke in the formation. In other instances, the H/C molar ratio may change depending on the type of asphaltene being produced in the formation.

[1014] In some embodiments, antioxidants (for example sulfates) are provided to a hydrocarbon formation to inhibit formation of coke. Antioxidants may be added to a hydrocarbon containing formation during formation of wellbores. For example, antioxidants may be added to drilling mud during drilling operations. Addition of antioxidants to the hydrocarbon formation may inhibit production of radicals during heating of the hydrocarbon formation, thus inhibiting production of higher molecular compounds (for example, coke).

[1015] Produced formation fluid may be separated into a liquid stream and a gas stream. The separated liquid stream may be blended with other hydrocarbon fractions, blended with additives to stabilize the asphaltenes, distilled, deasphalted, and/or filtered to remove components (for example, asphaltenes) that contribute to the instability of the liquid hydrocarbon stream. These treatments, however, may require costly solvents and/or be inefficient. Methods to produce liquid hydrocarbon streams that have good product stability are desired.

[1016] Adjustment of the asphaltene content of the hydrocarbons in situ may produce liquid hydrocarbon streams that require little to no treatment to stabilize the product with regard to precipitation of asphaltenes. In some embodiments, an asphaltene content of the hydrocarbons produced during an in situ heat treatment process may be adjusted in the formation. Changing an aliphatic content of the hydrocarbons in the formation may cause subsurface deasphalting and/or solubilization of asphaltenes in the hydrocarbons. Subsurface deasphalting of the hydrocarbons may produce solids that precipitate from the formation fluid and remain in the formation.

[1017] In some embodiments, heat from a plurality of heaters may be provided to a section located in the formation. The heat may transfer from the heaters to heat a portion of the section. In some embodiments, the portion of the section may be heated to a selected temperature (for example, the portion may be heated to about 220 °C, about 230 °C, or about 240 °C). Hydrocarbons in the section may be mobilized and produced from the formation. A portion of the produced hydrocarbons may be assessed using P-value, H/C molar ratio, and/or a volume ratio of naphtha/kerosene to hydrocarbons having a boiling point of at least 520 °C in a portion of produced formation fluids, and the stability of the produced hydrocarbons may be determined. Based on the assessed value, the asphaltene content and/or the asphaltenes H/C molar ratio of the hydrocarbons and/or a volume ratio of naphtha/kerosene to heavy hydrocarbons in a portion of fluids in the formation may be adjusted.

[1018] In some embodiments, the asphaltene content of the hydrocarbons may be adjusted based on a selected P-value. If the P-value is greater than a selected value (for example, greater than 1.1 or greater than 1.5), the hydrocarbons produced from the formation may be have acceptable asphaltene stability and the asphaltene content is not adjusted. If the P-value of the portion of the hydrocarbons is less than the selected value, the asphaltene content of the hydrocarbons in the formation may be adjusted.

[1019] In some embodiments, assessing the asphaltene H/C molar ratio in produced hydrocarbons may indicate that the type of asphaltenes in the hydrocarbons in the formation is changing. Adjustment of the asphaltene content of the hydrocarbons in the formation based on the asphaltenes H/C molar ratio in at least a portion of the produced hydrocarbons or when the asphaltenes H/C molar ratio reaches a selected value may produce liquid hydrocarbons that are

suitable for transportation or further processing. The asphaltene content may be adjusted when the asphaltene H/C molar ratio of at least a portion of the produced hydrocarbons is less than about 0.8, less than about 0.9, or less than about 1. An asphaltene H/C molar ratio of greater than 1 may indicate that the asphaltenes are soluble in the produced hydrocarbons. The asphaltene H/C molar ratio may be monitored over time and the asphaltene content may be adjusted at a rate to inhibit a net reduction of the assessed asphaltene H/C molar ratio over the monitored time period.

[1020] In some embodiments, a volume ratio of naphtha/kerosene to heavy hydrocarbons in the formation may be adjusted based on an assessed volume ratio of naphtha/kerosene to hydrocarbons having a boiling point of at least 520 °C in a portion of produced formation fluids. Adjustment of the volume ratio may allow a portion of the asphaltenes in the formation to precipitate from formation fluid and/or maintain the solubility of the asphaltenes in the produced hydrocarbons. An assessed value of a volume ratio of naphtha/kerosene to hydrocarbons having a boiling point of at least 520 °C of greater than 10 may indicate adjustment of the ratio is necessary. An assessed value of a volume ratio of naphtha/kerosene to hydrocarbons having a boiling point of at least 520 °C of from about 0 to about 10 may indicate that asphaltenes are sufficiently solubilized in the produced hydrocarbons. Solubilization of asphaltenes in hydrocarbons in the formation may inhibit a net reduction in a weight percentage of asphaltenes in hydrocarbons in the formation over time. Inhibiting a net reduction of asphaltenes may allow production of hydrocarbons that require no or minimal treatment to inhibit asphaltenes from precipitating from the produce hydrocarbons during transportation and/or further processing.

[1021] In some embodiments, the asphaltene content, asphaltene H/C molar ratio and/or volume ratio of naphtha/kerosene to heavy hydrocarbons may be adjusted by providing hydrocarbons to the formation. The hydrocarbons may include, but are not limited to, hydrocarbons having a boiling range distribution between 35 °C and 260 °C, hydrocarbons having a boiling range distribution between 38 °C and 200 °C (naphtha), hydrocarbons having a boiling range distribution between 204 °C and 260 °C (kerosene), bitumen, or mixtures thereof. The hydrocarbons may be provided to the section through a production well, injection well, heater well, monitoring well, or combinations thereof.

[1022] In some embodiments, the hydrocarbons added to the formation may be produced from an in situ heat treatment process. FIG. 121 is a representation of an embodiment of production and subsequent treating of a hydrocarbon formation to produce formation fluid. Heat from heaters 412 in hydrocarbon layer 388 may mobilize heavy hydrocarbons and/or bitumen towards production well 206A. Hydrocarbons may be produced from production well 206A and may

include liquid hydrocarbons having a boiling range distribution between 50 °C and 600 °C and/or bitumen.

[1023] Hydrocarbons used for in situ deasphalting may be injected into hydrocarbon layer 388 of the formation through injection well 602. Hydrocarbons may be injected at a sufficient pressure to allow mixing of the injected hydrocarbons with heavy hydrocarbons in hydrocarbon layer 388. Contact or mixing of hydrocarbons with heavy hydrocarbons in hydrocarbon layer 388 may remove at least a portion of the asphaltenes from the hydrocarbons in a section of the hydrocarbon layer. The resulting deasphalted hydrocarbons may be produced from the formation through production well 206B.

[1024] In some embodiment, contact or mixing of hydrocarbons with heavy hydrocarbons in hydrocarbon layer 388 may change the volume ratio of naphtha/kerosene to heavy hydrocarbons in the section such that the hydrocarbons produced from production well 206B are deemed suitable for transportation or processing as assessed by P-value, asphaltene H/C molar ratio, volume ratio of naphtha/kerosene to hydrocarbons having a boiling point greater than 520 °C or other methods known in the art to assess asphaltene stability.

[1025] In some embodiments, moving hydrocarbons from one section of the formation to another section of the formation may be used to adjust the asphaltene content and/or volume ratio of naphtha/kerosene to heavy hydrocarbons in the formation. In some embodiments, bitumen flows from section 1402 into section 1404 to change the volume ratio of naphtha/kerosene to heavy hydrocarbons to solubilize asphaltenes in the mobilized hydrocarbons present in section 1404. Solubilization of asphaltenes may inhibit a net reduction in a weight percentage of asphaltenes over time. The produced mobilized hydrocarbons may have an acceptable volume ratio of naphtha/kerosene to hydrocarbons having a boiling point greater than 520 °C and are deemed suitable for transportation or processing as assessed by P-value, asphaltene H/C molar ratio, volume ratio of naphtha/kerosene to hydrocarbons having a boiling point greater than 520 °C or other methods known in the art to assess asphaltene stability.

[1026] In some embodiments, a section of the formation is heated to a temperature sufficient to pyrolyze at least a portion of the formation fluids and generate hydrocarbons having a boiling point less than 260 °C. The generated hydrocarbons may act as an in situ deasphalting fluid. The generated hydrocarbons may move from a first section of the formation and mix with hydrocarbons in second section of the formation. Mixing of hydrocarbons having a boiling point less than 260 °C with mobilized hydrocarbons present in the formation may reduce the solubility of asphaltenes in the mobilized hydrocarbons and force at least a portion of the asphaltenes to precipitate from the mobilized hydrocarbons.

[1027] The precipitated asphaltenes may remain in the formation when the deasphalted mobilized hydrocarbons are produced from the formation. In some embodiments, the precipitated asphaltenes may form solid material. The produced deasphalted hydrocarbons may have acceptable P-values (for example, P-value greater than 1 or 1.5) and/or asphaltene H/C molar ratios (asphaltene H/C molar ratio of at least 1). The deasphalted hydrocarbons may be produced from the formation. The produced deasphalted hydrocarbons have acceptable asphaltene stability and are suitable for transportation or further processing. The produced deasphalted hydrocarbons may require no or very little treatment to inhibit asphaltene precipitation from the hydrocarbon stream when further processed.

[1028] In some embodiments, hydrocarbons having a boiling point less than 260 °C may be generated in a first section of the formation and migrate through an upper portion of the first section to an upper portion of a second section. In the upper portion of the second section, the hydrocarbons having a boiling point less than 260 °C may contact hydrocarbons in the second section of the formation. Such contact may remove at least a portion of the asphaltene from the hydrocarbons in the upper portion of second section. At least a portion of the deasphalted hydrocarbons may be produced from the formation.

[1029] In some embodiments, formation fluid may be produced from productions wells in a lower portion of the second section which may allow at least a portion of hydrocarbons having a boiling point less than 260 °C to drain to and, in some embodiments, condense in the lower portion of the second section. Contact of the hydrocarbons having a boiling point less than 260 °C with mobilized hydrocarbons in the lower portion of the second section may cause asphaltenes to precipitate from the hydrocarbons in the second section, thus removing asphaltenes from hydrocarbons in the second section. At least a portion of the deasphalted hydrocarbons may be produced from production wells in a lower portion of the second section. In some embodiments, deasphalted hydrocarbons are produced from other sections of the formation.

[1030] In some embodiments, contact of hydrocarbons having a boiling point less than 260 °C with mobilized hydrocarbons in the upper and/or lower portion of the second section may rebalance the naphtha/kerosene to heavy hydrocarbons volume ratio and solubilize asphaltenes in the mobilized hydrocarbons in the section. Solubilization of asphaltenes may inhibit a net reduction in a weight percentage of asphaltenes over time and, thus produce a more stabile product. Mobilized hydrocarbons may be produced from the formation. The mobilized hydrocarbons produced from the second section may be exhibit more stabile properties than mobilized hydrocarbons produced from the first section.

[1031] Generation and migration of hydrocarbons having a boiling point less than 260°C may be selectively controlled using operating conditions (for example, heating rate, average temperatures in the formation, and production rates) in the first, second and/or third sections.

[1032] FIG. 122 is a representation of an embodiment of production of in situ deasphalting fluid and use of the in situ deasphalting fluid in treating a hydrocarbon formation using an in situ heat treatment process. Heaters 412 in hydrocarbon layer 388 may provide heat to one or more sections of the hydrocarbon layer. Heaters 412 may be substantially horizontal in the hydrocarbon layer. Heaters 412 may be arranged in any pattern to optimize heating of portions of first section 1406 and/or portions of second section 1408. Bitumen and/or liquid hydrocarbons may be produced from a lower portion of first section 1406 through production wells 206A. The temperature in the lower portion of first section 1406 may be raised to a pyrolysis temperature and pyrolysis of formation fluid in the lower portion may generate an in situ deasphalting fluid. The in situ deasphalting fluid may be a mixture of hydrocarbons having a boiling range distribution between -5 °C and about 300 °C, or between -5 °C and about 260 °C.

[1033] In some embodiments, production well and/or other wells in first section 1406 may be shut in to allow the in situ deasphalting fluid to mix with hydrocarbons in the lower portion of the first section. The in situ deasphalting fluid may contact hydrocarbons in first section 1406 and cause at least a portion of asphaltenes to precipitate from the hydrocarbons, thus removing the asphaltenes from the hydrocarbons in the formation. The deasphalted hydrocarbons may be mobilized and produced from the formation through production wells 206B in an upper portion of first section 1406.

[1034] At least a portion of in situ deasphalting fluid vaporizes in the upper portion of first section 1406 and move towards an upper portion of second section 1408 as shown by arrows 1410. An average temperature in second section 1408 may be lower than an average temperature of first section 1406. Due to the lower temperature in second section 1408, the in situ deasphalting fluid may condense in the second section. The temperature and pressure in second section 1408 may be controlled such that substantially all of the in situ deasphalting fluid is present as a liquid in the second section. The in situ deasphalting fluid may contact hydrocarbons in second section 1408 and cause asphaltenes to precipitate from the hydrocarbons in the section, thus removing asphaltenes from hydrocarbons in the second section. At least a portion of the deasphalted hydrocarbons may be produced from the formation through production wells 206C in an upper portion of second section 1408. In some embodiments, deasphalted hydrocarbons are moved to a third section of hydrocarbon layer 388 and produced from the third section.

[1035] In some embodiments, formation fluid may be produced from productions wells 206D in a lower portion of second section 1408. Production of formation fluid from production wells 206D in the lower portion of second section 1408 may allow at least a portion of the in situ deasphalting fluid to drain to the lower portion of the second section. Contact of the in situ deasphalting fluid with hydrocarbons in a lower portion of second section 1408 may cause asphaltenes to precipitate from the hydrocarbons in the section, thus removing asphaltenes from hydrocarbons in the second section. At least a portion of the deasphalted hydrocarbons may be produced from production wells 206E in the middle portion of second section 1408. In some embodiments, deasphalted hydrocarbons are not produced in second section 1408, but flow or be moved towards a third section in hydrocarbon layer 388 and produced from the third section. The third section may be substantially below or substantially adjacent to second section 1408.

[1036] Deasphalted hydrocarbons produced from the formation may be suitable for transportation, have a P-value greater than 1.5, and/or an asphaltene H/C molar ratio of at least 1. In some embodiments, the produced deasphalted hydrocarbons contain at least a portion of the in situ deasphalting fluid.

[1037] In some embodiments, the in situ deasphalting fluid mixes with mobilized hydrocarbons and changes the volume ratio of naphtha/kerosene to heavy hydrocarbons such that asphaltenes are solubilized in the mobilized hydrocarbons. At least a portion of the hydrocarbons containing solubilized asphaltenes may be produced from production wells 206E in a bottom portion of second section 1408. In some embodiments, hydrocarbons containing solubilized asphaltenes are produced from a third section of the formation. Hydrocarbons containing solubilized asphaltenes produced from the formation may be suitable for transportation, have a P-value greater than 1.5, and/or an asphaltene H/C molar ratio of at least 1. In some embodiments, the produced hydrocarbons containing solubilized asphaltenes contain at least a portion of the in situ deasphalting fluid.

[1038] The in situ heat treatment process may provide less heat to the formation (for example, use a wider heater spacing) if the in situ heat treatment process is followed by a drive process. The drive process may involve introducing a hot fluid into the formation to increase the amount of heat provided to the formation. In some embodiments, the heaters of the in situ heat treatment process may be used to pretreat the formation to establish injectivity for the subsequent drive process. In some embodiments, the in situ heat treatment process creates or produces the drive fluid in situ. The in situ produced drive fluid may move through the formation and move mobilized hydrocarbons from one portion of the formation to another portion of the formation.

[1039] FIG. 123 depicts a top view representation of an embodiment for preheating using heaters before using the drive process (for example, a steam drive process). Injection wells 602 and

production wells 206 are substantially vertical wells. Heaters 412 are long substantially horizontal heaters positioned so that the heaters pass in the vicinity of injection wells 602. Heaters 412 intersect the vertical well patterns slightly displaced from the vertical wells.

[1040] The vertical location of heaters 412 with respect to injection wells 602 and production wells 206 depends on, for example, the vertical permeability of the formation. In formations with at least some vertical permeability, injected steam will rise to the top of the permeable layer in the formation. In such formations, heaters 412 may be located near the bottom of the hydrocarbon layer 388, as shown in FIG. 124. In formations with very low vertical permeabilities, more than one horizontal heater may be used with the heaters stacked substantially vertically or with heaters at varying depths in the hydrocarbon layer (for example, heater patterns as shown in FIGS. 117-120). The vertical spacing between the horizontal heaters in such formations may correspond to the distance between the heaters and the injection wells. Heaters 412 are located in the vicinity of injection wells 602 and/or production wells 206 so that sufficient energy is delivered by the heaters to provide flow rates for the drive process that are economically viable. The spacing between heaters 412 and injection wells 602 or production wells 206 may be varied to provide an economically viable drive process. The amount of preheating may also be varied to provide an economically viable process.

[1041] In some embodiments, the steam injection (or drive) process (for example, SAGD, cyclic steam soak, or another steam recovery process) is used to treat the formation and produce hydrocarbons from the formation. The steam injection process may recover a low amount of oil in place from the formation (for example, less than 20% recovery of oil in place from the formation). The in situ heat treatment process may be used following the steam injection process to increase the recovery of oil in place from the formation. In certain embodiments, the steam injection process is used until the steam injection process is no longer efficient at removing hydrocarbons from the formation (for example, until the steam injection process is no longer economically feasible). The in situ heat treatment process is used to produce hydrocarbons remaining in the formation after the steam injection process. Using the in situ heat treatment process after the steam injection process may allow recovery of at least about 25%, at least about 50%, at least about 55%, or at least about 60% of oil in place in the formation.

[1042] In some embodiments, the formation has been at least somewhat heated by the steam injection process before treating the formation using the in situ heat treatment process. For example, the steam injection process may heat the formation to an average temperature between about 200 °C and about 250 °C, between about 175 °C and about 265 °C, or between about 150 °C and about 270 °C. In certain embodiments, the heaters are placed in the formation after the steam injection process is at least 50% completed, at least 75% completed, or near 100%

completed. The heaters provide heat for treating the formation using the in situ heat treatment process. In some embodiments, the heaters are already in place in the formation during the steam injection process. In such embodiments, the heaters may be energized after the steam injection process is completed or when production of hydrocarbons using the steam injection process is reduced below a desired level. In some embodiments, steam injection wells from the steam injection process are converted to heater wells for the in situ heat treatment process.

[1043] Treating the formation with the in situ heat treatment process after the steam injection process may be more efficient than only treating the formation with the in situ heat treatment process. The steam injection process may provide some energy (heat) to the formation with the steam. Any energy added to the formation during the steam injection process reduces the amount of energy needed to be supplied by heaters for the in situ heat treatment process. Reducing the amount of energy supplied by heaters reduces costs for treating the formation using the in situ heat treatment process.

[1044] In certain embodiments, treating the formation using the steam injection process does not treat the formation uniformly. For example, steam injection may not be uniform throughout the formation. Variations in the properties of the formation (for example, fluid injectivities, permeabilities, and/or porosities) may result in non-uniform injection of the steam through the formation. Because of the non-uniform injection of the steam, the steam may remove hydrocarbons from different portions of the formation at different rates or with different results. For example, some portions of the formation may have little or no steam injectivity, which inhibits the hydrocarbon production from these portions. After the steam injection process is completed, the formation may have portions that have lower amounts of hydrocarbons produced (more hydrocarbons remaining) than other parts of the formation.

[1045] FIG. 125 depicts a side view representation of an embodiment of a tar sands formation subsequent to a steam injection process. Injection well 602 is used to inject steam into hydrocarbon layer 388 below overburden 400. Portion 604 may have little or no steam injectivity and have small amounts of hydrocarbons or no hydrocarbons at all removed by the steam injection process. Portions 606 may include portions that have steam injectivity and measurable amounts of hydrocarbons are removed by the steam injection process. Thus, portion 604 may have a greater amount of hydrocarbons remaining than portions 606 following treatment with the steam injection process. In some embodiments, hydrocarbon layer 388 includes two or more portions 604 with more hydrocarbons remaining than portions 606.

[1046] In some embodiments, the portions with more hydrocarbons remaining (such as portion 604, depicted in FIG. 125) are large portions of the formation. In some embodiments, the amount of hydrocarbons remaining in these portions is significantly higher than other portions of

the formation (such as portions 606). For example, portions 604 may have a recovery of at most about 10% of the oil in place and portions 606 may have a recovery of at least about 30% of the oil in place. In some embodiments, portions 604 have a recovery of between about 0% and about 10% of the oil in place, between about 0% and about 15% of the oil in place, or between about 0% and about 20% of the oil in place. The portions 606 may have a recovery of between about 20% and about 25% of the oil in place, between about 20% and about 40% of the oil in place, or between about 20% and about 50% of the oil in place. Coring, logging techniques, and/or seismic imaging may be used to assess hydrocarbons remaining in the formation and assess the location of one or more of the first and/or second portions.

[1047] In certain embodiments, during the in situ heat treatment process, more heat is provided to the first portions of the formation that have more hydrocarbons remaining than the second portions with less hydrocarbons remaining. In some embodiments, heaters are located in the first portions but not in the second portions. In some embodiments, heaters are located in both the first portions and the second portions but the heaters in the first portions are designed or operated to provide more heat than the heaters in the second portions. In some embodiments, heaters pass through both first portions and second portions and the heaters are designed or operated to provide more heat in the first portions than the second portions.

[1048] In some embodiments, steam injection is continued during the in situ heat treatment process. For example, steam injection may be continued while liquids are being produced from the formation. The steam injection may increase the production of liquids from the formation. In certain embodiments, steam injection may be reduced or stopped when gas production from the formation begins.

[1049] In some embodiments, the formation is treated using the in situ heat treatment process a significant time after the formation has been treated using the steam injection process. For example, the in situ heat treatment process is used 1 year, 2 years, 3 years, or longer (for example, 10 years to 20 years) after a formation has been treated using the steam injection process. During this dormant period, heat from the steam injection process may diffuse to cooler parts of the formation and result in a more uniform preheating of the formation prior to in situ heat treatment. The in situ heat treatment process may be used on formations that have been left dormant after the steam injection process treatment because further hydrocarbon production using the steam injection process is not possible and/or not economically feasible. In some embodiments, the formation remains at least somewhat heated from the steam injection process even after the significant time.

[1050] In certain embodiments, a fluid is injected into the formation (for example, a drive fluid or an oxidizing fluid) to move hydrocarbons through the formation from a first section to a

second section. In some embodiments, the hydrocarbons are moved from the first section to the second section through a third section. FIG. 126 depicts a side view representation of an embodiment using at least three treatment sections in a tar sands formation. Hydrocarbon layer 388 may be divided into three or more treatment sections. In certain embodiments, hydrocarbon layer 388 includes three different types of treatment sections: section 608A, section 608B, and section 608C. Section 608C and sections 608A are separated by sections 608B. Section 608C, sections 608A, and sections 608B may be horizontally displaced from each other in the formation. In some embodiments, one side of section 608C is adjacent to an edge of the treatment area of the formation or an untreated section of the formation is left on one side of section 608C before the same or a different pattern is formed on the opposite side of the untreated section.

[1051] In certain embodiments, sections 608A and 608C are heated at or near the same time to similar temperatures (for example, pyrolysis temperatures). Sections 608A and 608C may be heated to mobilize and/or pyrolyze hydrocarbons in the sections. The mobilized and/or pyrolyzed hydrocarbons may be produced (for example, through one or more production wells) from section 608A and/or section 608C. Section 608B may be heated to lower temperatures (for example, mobilization temperatures). Little or no production of hydrocarbons to the surface may take place through section 608B. For example, sections 608A and 608C may be heated to average temperatures of about 300 °C while section 608B is heated to an average temperature of about 100 °C and no production wells are operated in section 608B.

[1052] In certain embodiments, heating and producing hydrocarbons from section 608C creates fluid injectivity in the section. After fluid injectivity has been created in section 608C, a fluid such as a drive fluid (for example, steam, water, or hydrocarbons) and/or an oxidizing fluid (for example, air, oxygen, enriched air, or other oxidants) may be injected into the section. The fluid may be injected through heaters 412, a production well, and/or an injection well located in section 608C. In some embodiments, heaters 412 continue to provide heat while the fluid is being injected. In other embodiments, heaters 412 may be turned down or off before or during fluid injection.

[1053] In some embodiments, providing oxidizing fluid such as air to section 608C causes oxidation of hydrocarbons in the section. For example, coked hydrocarbons and/or heated hydrocarbons in section 608C may oxidize if the temperature of the hydrocarbons is above an oxidation ignition temperature. In some embodiments, treatment of section 608C with the heaters creates coked hydrocarbons with substantially uniform porosity and/or substantially uniform injectivity so that heating of the section is controllable when oxidizing fluid is introduced to the section. The oxidation of hydrocarbons in section 608C will maintain the

average temperature of the section or increase the average temperature of the section to higher temperatures (for example, about 400 °C or above).

[1054] In some embodiments, injection of the oxidizing fluid is used to heat section 608C and a second fluid is introduced into the formation after or with the oxidizing fluid to create drive fluids in the section. During injection of oxidant, excess oxidant and/or oxidation products may be removed from section 608C through one or more production wells. After the formation is raised to a desired temperature, a second fluid may be introduced into section 608C to react with coke and/or hydrocarbons and generate drive fluid (for example, synthesis gas). In some embodiments, the second fluid includes water and/or steam. Reactions of the second fluid with carbon in the formation may be endothermic reactions that cool the formation. In some embodiments, oxidizing fluid is added with the second fluid so that some heating of section 608C occurs simultaneous with the endothermic reactions. In some embodiments, section 608C may be treated in alternating steps of adding oxidant to heat the formation, and then adding second fluid to generate drive fluids.

[1055] The generated drive fluids in section 608C may include steam, carbon dioxide, carbon monoxide, hydrogen, methane, and/or pyrolyzed hydrocarbons. The high temperature in section 608C and the generation of drive fluid in the section may increase the pressure of the section so the drive fluids move out of the section into adjacent sections. The increased temperature of section 608C may also provide heat to section 608B through conductive heat transfer and/or convective heat transfer from fluid flow (for example, hydrocarbons and/or drive fluid) to section 608B.

[1056] In some embodiments, hydrocarbons (for example, hydrocarbons produced from section 608C) are provided as a portion of the drive fluid. The injected hydrocarbons may include at least some pyrolyzed hydrocarbons such as pyrolyzed hydrocarbons produced from section 608C. In some embodiments, steam or water are provided as a portion of the drive fluid. Steam or water in the drive fluid may be used to control temperatures in the formation. For example, steam or water may be used to keep temperatures lower in the formation. In some embodiments, water injected as the drive fluid is turned into steam in the formation due to the higher temperatures in the formation. The conversion of water to steam may be used to reduce temperatures or maintain lower temperatures in the formation.

[1057] Fluids injected in section 608C may flow towards section 608B, as shown by the arrows in FIG. 126. Fluid movement through the formation transfers heat convectively through hydrocarbon layer 388 into sections 608B and/or 608A. In addition, some heat may transfer conductively through the hydrocarbon layer between the sections.

[1058] Low level heating of section 608B mobilizes hydrocarbons in the section. The mobilized hydrocarbons in section 608B may be moved by the injected fluid through the section towards section 608A, as shown by the arrows in FIG. 126. Thus, the injected fluid is pushing hydrocarbons from section 608C through section 608B to section 608A. Mobilized hydrocarbons may be upgraded in section 608A due to the higher temperatures in the section. Pyrolyzed hydrocarbons that move into section 608A may also be further upgraded in the section. The upgraded hydrocarbons may be produced through production wells located in section 608A.

[1059] In certain embodiments, at least some hydrocarbons in section 608B are mobilized and drained from the section prior to injecting the fluid into the formation. Some formations may have high oil saturation (for example, the Grosmont formation has high oil saturation). The high oil saturation corresponds to low gas permeability in the formation that may inhibit fluid flow through the formation. Thus, mobilizing and draining (removing) some oil (hydrocarbons) from the formation may create gas permeability for the injected fluids.

[1060] Fluids in hydrocarbon layer 388 may preferentially move horizontally within the hydrocarbon layer from the point of injection because tar sands tend to have a larger horizontal permeability than vertical permeability. The higher horizontal permeability allows the injected fluid to move hydrocarbons between sections preferentially versus fluids draining vertically due to gravity in the formation. Providing sufficient fluid pressure with the injected fluid may ensure that fluids are moved to section 608A for upgrading and/or production.

[1061] In certain embodiments, section 608B has a larger volume than section 608A and/or section 608C. Section 608B may be larger in volume than the other sections so that more hydrocarbons are produced for less energy input into the formation. Because less heat is provided to section 608B (the section is heated to lower temperatures), having a larger volume in section 608B reduces the total energy input to the formation per unit volume. The desired volume of section 608B may depend on factors such as, but not limited to, viscosity, oil saturation, and permeability. In addition, the degree of coking is much less in section 608B due to the lower temperature so less hydrocarbons are coked in the formation when section 608B has a larger volume. In some embodiments, the lower degree of heating in section 608B allows for cheaper capital costs as lower temperature materials (cheaper materials) may be used for heaters used in section 608B.

[1062] Certain types of formations have low initial matrix permeabilities and contain formation fluid having high initial viscosities at initial or ambient condition that inhibit these formations from being easily treated using conventional steam drive processes such as SAGD or CSS. For example, carbonate formations (such as the Grosmont reservoir in Alberta, Canada) have low

matrix permeabilities and contain formation fluid with high viscosities that make these formations unsuitable for conventional steam drive processes. Carbonate formations may also be highly heterogenous (for example, have highly different vertical and horizontal permeabilities), which makes it difficult to control flow of fluids (such as steam) through the formation. In addition, some carbonate formations are relatively shallow formations with low overburden fracture pressures that inhibit the use of high pressure steam injection because of the need to avoid breaking or fracturing the overburden.

[1063] In certain embodiments, formations with the above properties (such as the Grosmont reservoir or other carbonate formations) are treated using a combination of heating from heaters and steam drive processes. FIG. 127 depicts an embodiment for treating a formation with heaters in combination with one or more steam drive processes. Heater 412A is located in hydrocarbon containing layer 388 between injection well 602 and production well 206. Injection well 602 and production well 206 may be used to inject steam and produce hydrocarbons, respectively, in a steam drive process, such as a SAGD (steam assisted gravity drainage) process. In certain embodiments, heater 412A is located substantially horizontally in layer 388. In some embodiments, injection well 602 and production well 206 are located substantially horizontally in layer 388.

[1064] In certain embodiments, heater 412A is located approximately vertically equidistant between injection well 602 and production well 206 (the heater is at or near the midpoint between the injection well and the production well). Heater 412A may provide heat to a portion of layer 388 surrounding the heater and proximate injection well 602 and production well 206. In some embodiments, heater 412A is an electric heater such as an insulated conductor heater or a conductor-in-conduit heater. In certain embodiments, heat provided by heater 412A increases the steam injectivity in the portion surrounding the heater. In certain embodiments, heater 412A provides heat at high heat injection rates such as those used for the in situ heat treatment process (for example, heat injection rates of at least about 1000 W/m).

[1065] As shown in FIG. 127, in certain embodiments, heater 412B is located above injection/production well 610. In certain embodiments, heater 412B is located substantially horizontally in layer 388.

[1066] In certain embodiments, injection/production well 610 is at least partially offset from heater 412B. Injection/production well 610 may be used to inject steam and produce hydrocarbons in a cyclic steam drive process, such as a CSS (cyclic steam injection) process. Heater 412B may provide heat to a portion of layer 388 surrounding the heater and proximate injection/production well 610. In some embodiments, heater 412B is an electric heater such as an insulated conductor heater or a conductor-in-conduit heater. In certain embodiments, heat

provided by heater 412B increases the steam injectivity in the portion surrounding the heater. In certain embodiments, heater 412B provides heat at high heat injection rates such as those used for the in situ heat treatment process (for example, heat injection rates of at least about 1000 W/m).

[1067] In certain embodiments, layer 388 has different initial vertical and horizontal matrix permeabilities (the initial matrix permeability is heterogenous). In one embodiment, the initial vertical matrix permeability in layer 388 is at most about 300 millidarcy and the initial horizontal matrix permeability is at most about 1 darcy. In some carbonate formations, the initial vertical matrix permeability is less than the initial horizontal matrix permeability such as, for example, in the Grosmont reservoir in Alberta, Canada. The initial vertical and initial horizontal matrix permeabilities may vary depending on the location in the formation and/or the type of formation. In one embodiment, layer 388 includes formation fluid (for example, hydrocarbons) having an initial viscosity of at least about 1×10^6 centipoise (cp). The initial viscosity may vary depending on the location or depth of the fluid in the formation.

[1068] Typically, these initial permeabilities and initial viscosities are not favorable for steam injection into layer 388 because the steam injection pressure needed to get steam to move hydrocarbons through the formation is above the fracture pressure of overburden 400. Staying below the overburden fracture pressure may be especially difficult for shallower formations such as the Grosmont reservoir because the overburden fracture pressure is relatively small in such shallower formations. In certain embodiments, heater 412A and/or heater 412B are used to provide heat to layer 388 to reduce the viscosity of formation fluid in the portion surrounding the heater such that steam injected into the layer at pressures below the overburden fracture pressure can move hydrocarbons in the layer. Thus, providing heat to the layer increases the steam injectivity in the layer.

[1069] In certain embodiments, a selected amount of heat, or selected amount of heating time, is provided from heater 412A and/or heater 412B to reduce the viscosity of the formation fluid in layer 388 before steam injection through injection well 602 or injection/production well 610 begins. In some embodiments, a simulation of reservoir conditions is used to assess or determine the selected amount of heat, or heating time, needed before steam injection into layer 388. For example, the selected amount of heating time for heater 412A may be about 1 year for layer 388 to have mobilities or viscosities suitable for steam injection (sufficient steam injectivity is created in the layer) through injection well 602. The selected amount of heating time for heater 412B may be about 1 year for layer 388 to have mobilities or viscosities suitable for steam injection (sufficient steam injectivity is created in the layer) through injection/production well 610.

[1070] In certain embodiments, heater 412A is turned off before steam injection begins. In other embodiments, heater 412A is turned off after steam injection begins. In some embodiments, heater 412A is turned off a selected amount of time after steam injection begins. The time the heater is turned off may be selected to provide, for example, desired properties in the hydrocarbons produced from the formation.

[1071] In certain embodiments, heater 412B remains on for a selected amount of time after steam injection/hydrocarbon production through injection/production well 610 begins. Heater 412B may remain on to maintain steam injectivity in the portion surrounding the heater and injection/production well 610. In some embodiments, heat provided from heater 412B increases the size of the portion with increased steam injectivity. After a period of time, heat provided from heater 412B may create steam injection interconnectivity between injection/production well 610 and production well 206. After interconnectivity between injection/production well 610 and production well 206 is achieved, heater 412B may be turned off.

[1072] Interconnectivity between injection/production well 610 and production well 206 allows steam injection from the injection/production well to move hydrocarbons to the production well. This hydrocarbon movement may increase the efficiency of steam injection and hydrocarbon production from the layer. The interconnectivity may also allow less injection wells and/or production wells to be used in treating the layer.

[1073] In certain embodiments, heating from heater 412A and/or heater 412B is controlled and/or turned off at a time to inhibit coke formation in the layer. Simulation of reservoir conditions may be used to determine when/if the onset of coking may occur in the layer. Additionally, steam injection into the formation may assist in inhibiting coke formation in the layer.

[1074] In certain embodiments, steam is injected through injection well 602 at a pressure below the pressure of steam injected through injection/production well 610 (for example, at least 0.5 MPa below the pressure of steam injected through the injection/production well). In certain embodiments, steam is injected through injection well 602 and/or injection/production well 610 at a pressure that is above the formation fracturing pressure but below the overburden fracture pressure. Injecting steam above the formation fracturing pressure may increase the permeability and/or move steam or hydrocarbons through the formation at higher rates. Thus, injecting steam above the formation fracturing pressure may increase the rate of hydrocarbon production through production well 206 and/or injection/production well 610. Injecting steam below the overburden fracture pressure inhibits the steam from fracturing the overburden and allowing formation fluids to escape to the surface through the overburden (for example, maintains the integrity of the overburden).

[1075] In some embodiments, a pattern for treating a formation includes a repeating pattern of heaters 412A, 412B, injection well 602, production well 206, and injection/production well 610, as shown in FIG. 127. The pattern may be repeated horizontally and/or vertically in the formation. Using the repeating pattern to treat the formation may reduce the number of wells needed to treat the formation as compared to using typical steam drive processes or in situ heat treatment processes individually. In some embodiments, heaters 412A, 412B may be removed and reused in another portion of the formation, or another formation, after the heaters are turned off. The heaters may be allowed to cool down before being removed from the formation.

[1076] Using the embodiment depicted in FIG. 127 to treat the formation (for example, the Grosmont reservoir) may increase oil production and/or decrease the amount of steam needed for oil production as compared to using the SAGD process only. FIG. 128 depicts a comparison treating the formation using the embodiment depicted in FIG. 127 and treating the formation using the SAGD process. Cumulative oil production, cumulative steam-oil ratio, and top pressure for the formation are compared using the two techniques. Plot 612 depicts cumulative oil production for the embodiment depicted in FIG. 127. Plot 614 depicts cumulative oil production for the SAGD process. Plot 616 depicts cumulative steam-oil ratio for the embodiment depicted in FIG. 127. Plot 618 depicts cumulative steam-oil ratio for the SAGD process. Plot 620 depicts top pressure for the embodiment depicted in FIG. 127. Plot 622 depicts top pressure for the SAGD process. As shown in FIG. 128, cumulative oil production is significantly increased for the embodiment depicted in FIG. 127 while the steam-oil ratio is slightly decreased and the top pressure is substantially the same. Thus, the embodiment depicted in FIG. 127 is more efficient in producing oil than the SAGD process.

[1077] In some embodiments, karsted formations or karsted layers in formations have vugs in one or more layers of the formations. The vugs may be filled with viscous fluids such as bitumen or heavy oil. In some embodiments, the karsted layers have a porosity of at least about 20 porosity units, at least about 30 porosity units, or at least about 35 porosity units. The karsted formation may have a porosity of at most about 15 porosity units, at most about 10 porosity units, or at most about 5 porosity units. Vugs filled with viscous fluids may inhibit steam or other fluids from being injected into the formation or the layers. In certain embodiments, the karsted formation or karsted layers of the formation are treated using the in situ heat treatment process.

[1078] Heating of these formations or layers may decrease the viscosity of the viscous fluids in the vugs and allow the fluids to drain (for example, mobilize the fluids). Formations with karsted layers may have sufficient permeability so that when the viscosity of fluids (hydrocarbons) in the formation is reduced, the fluids drain and/or move through the formation relatively easily (for example, without a need for creating higher permeability in the formation).

[1079] In some embodiments, the relative amount (the degree) of karst in the formation is assessed using techniques known in the art (for example, 3D seismic imaging of the formation). The assessment may give a profile of the formation showing layers or portions with varying amounts of karst in the formation. In certain embodiments, more heat is provided to selected karsted portions of the formation than other karsted portions of the formation. In some embodiments, selective amounts of heat are provided to portions of the formation as a function of the degree of karst in the portions. Amounts of heat may be provided by varying the number and/or density of heaters in the portions with varying degrees of karst.

[1080] In certain embodiments, the hydrocarbon fluids in karsted portions have higher viscosities than hydrocarbons in other non-karsted portions of the formation. Thus, more heat may be provided to the karsted portions to reduce the viscosity of the hydrocarbons in the karsted portions.

[1081] In certain embodiments, only the karsted layers of the formation are treated using the in situ heat treatment process. Other non-karsted layers of the formation may be used as seals for the in situ heat treatment process. For example, karsted layers with different quantities of hydrocarbons in the layers may be treated while other layers are used as natural seals for the treatment process. In some embodiments, karsted layers with low quantities of hydrocarbons as compared to the other karsted and/or non-karsted layers are used as seals for the treatment process. The quantity of hydrocarbons in the Karsted layer may be determined using logging methods and/or Dean Stark distillation methods. The quantity of hydrocarbons may be reported as a volume percent of hydrocarbons per volume percent of rock, or as volume of hydrocarbons per mass of rock.

[1082] In some embodiments, karsted layers with fewer hydrocarbons are treated along with karsted layers with more hydrocarbons. In some embodiments, karsted layers with fewer hydrocarbons are above and below a karsted layer with more hydrocarbons (the middle karsted layer). Less heat may be provided to the upper and lower karsted layers than the middle karsted layer. Less heat may be provided in the upper and lower karsted layers by having greater heat spacing and/or less heaters in the upper and lower karsted layers as compared to the middle karsted layer. In some embodiments, less heating of the upper and lower karsted layers includes heating the layers to mobilization and/or visbreaking temperatures, but not to pyrolysis temperatures. In some embodiments, the upper and/or lower karsted layers are heated with heaters and the residual heat from the upper and/or lower layers transfers to the middle layer.

[1083] One or more production wells may be located in the middle karsted layer. Mobilized and/or visbroken hydrocarbons from the upper karsted layer may drain to the production wells in the middle karsted layer. Heat provided to the lower karsted layer may create a thermal

expansion drive and/or a gas pressure drive in the lower karsted layer. The thermal expansion and/or gas pressure may drive fluids from the lower karsted layer to the middle karsted layer. These fluids may be produced through the production wells in the middle karsted layer. Providing some heat to the upper and lower karsted layers may increase the total recovery of fluids from the formation by, for example, 25% or more.

[1084] In some embodiments, the karsted layers with fewer hydrocarbons are further heated to pyrolysis temperatures after production from the karsted layer with more hydrocarbons is completed or almost completed. The karsted layers with fewer hydrocarbons may also be further treated by producing fluids through production wells located in the layers.

[1085] In some embodiments, a drive process, a solvent injection process and/or a pressurizing fluid process is used after the in situ heat treatment of the karsted formation or karsted layers. A drive process may include injection of a drive fluid such as steam. A drive process includes, but is not limited to, a steam injection process such as cyclic steam injection, a steam assisted gravity drainage process (SAGD), and a vapor solvent and SAGD process. A drive process may drive fluids from one portion of the formation towards a production well.

[1086] A solvent injection process may include injection of a solvating fluid. A solvating fluid includes, but is not limited to, water, emulsified water, hydrocarbons, surfactants, alkaline water solutions (for example, sodium carbonate solutions), caustic, polymers, carbon disulfide, carbon dioxide, or mixtures thereof. The solvation fluid may mix with, solvate and/or dilute the hydrocarbons to form a mixture of condensable hydrocarbons and solvation fluids. The mixture may have a reduced viscosity as compared to the initial viscosity of the fluids in the formation. The mixture may flow and/or be mobilized towards production wells in the formation.

[1087] A pressurizing process may include moving hydrocarbons in the formation by injection of a pressurized fluid. The pressurizing fluid may include, but is not limited to, carbon dioxide, nitrogen, steam, methane, and/or mixtures thereof.

[1088] In some embodiments, the drive process (for example, the steam injection process) is used to mobilize fluids before the in situ heat treatment process. Steam injection may be used to get hydrocarbons (oil) away from rock or other strata in the formation. The steam injection may mobilize the hydrocarbons without significantly heating the rock.

[1089] In some embodiments, fluid injected in the formation (for example, steam and/or carbon dioxide) may absorb heat from the formation and cool the formation depending on the pressure in the formation and the temperature of the injected fluid. In some embodiments, the injected fluid is used to recover heat from the formation. The recovered heat may be used in surface processing fluids and/or to preheat other portions of the formation using the drive process.

[1090] In some embodiments, heaters are used to preheat the karsted formation or karsted layers to create injectivity in the formation. In situ heat treatment of karsted formations and/or karsted layers may allow for drive fluid injection, solvent injection and/or pressurizing fluid injection where it was previously unfavorable or unmanageable. Typically, karsted formations were unfavorable for drive processes because channeling of the fluid injected in the formation inhibited pressure build-up in the formation. In situ heat treatment of karsted formations may allow for injection of a drive fluid, a solvent and/or a pressurizing fluid by reducing the viscosity of hydrocarbons in the formation and allowing pressure to build in the formations without significant bypass of the fluid through channels in the formations. For example, heating a section of the formation using in situ heat treatment may heat and mobilize heavy hydrocarbons (bitumen) by reducing the viscosity of the heavy hydrocarbons in the karsted layer. Some of the heated less viscous heavy hydrocarbons may flow from the karsted layer into other portions of the formation that are cooler than the heated karsted portion. The heated less viscous heavy hydrocarbons may flow through channels and/or fractures. The heated heavy hydrocarbons may cool and solidify in the channels, thus creating a temporary seal for the drive fluid, solvent, and/or pressurizing fluid.

[1091] In certain embodiments, the karsted formation or karsted layers are heated to temperatures below the decomposition temperature of minerals in the formation (for example, rock minerals such as dolomite and/or clay minerals such as kaolinite, illite, or smectite). In some embodiments, the karsted formation or karsted layers are heated to temperatures of at most 400 °C, at most 450 °C, or at most 500 °C (for example, to a temperature below a dolomite decomposition temperature at formation pressure). In some embodiments, the karsted formation or karsted layers are heated to temperatures below a decomposition temperature of clay minerals (such as kaolinite) at formation pressure.

[1092] In some embodiments, heat is preferentially provided to portions of the formation with low weight percentages of clay minerals (for example, kaolinite) as compared to the content of clay in other portions of the formation. For example, more heat may be provided to portions of the formation with at most 1% by weight clay minerals, at most 2% by weight clay minerals, or at most 3% by weight clay minerals than portions of the formation with higher weight percentages of clay minerals. In some embodiments, the rock and/or clay mineral distribution is assessed in the formation prior to designing a heater pattern and installing the heaters. The heaters may be arranged to preferentially provide heat to the portions of the formation that have been assessed to have lower weight percentages of clay minerals as compared to other portions of the formation. In certain embodiments, the heaters are placed substantially horizontally in layers with low weight percentages of clay minerals.

[1093] Providing heat to portions of the formation with low weight percentages of clay minerals may minimize changes in the chemical structure of the clays. For example, heating clays to high temperatures may drive water from the clays and change the structure of the clays. The change in structure of the clay may adversely affect the porosity and/or permeability of the formation. If the clays are heated in the presence of air, the clays may oxidize and the porosity and/or permeability of the formation may be adversely affected. Portions of the formation with a high weight percentage of clay minerals may be inhibited from reaching temperatures above temperatures that effect the chemical composition of the clay minerals at formation pressures. For example, portions of the formation with large amounts of kaolinite relative to other portions of the formation may be inhibited from reaching temperatures above 240 °C. In some embodiments, portions of the formation with a high quantity of clay minerals relative to other portions of the formation may be inhibited from reaching temperatures above 200 °C, above 220 °C, above 240 °C, or above 300 °C.

[1094] In some embodiments, karsted formations may include water. Minerals (for example, carbonate minerals) in the formation may at least partially dissociate in the water to form carbonic acid. The concentration of carbonic acid in the water may be sufficient to make the water acidic. At pressure greater than ambient formation pressures, dissolution of minerals in the water may be enhanced, thus formation of acidic water is enhanced. Acidic water may react with other minerals in the formation such as dolomite ($MgCa(CO_3)_2$) and increase the solubility of the minerals. Water at lower pressures, or non-acidic water, may not solubilize the minerals in the formation. Dissolution of the minerals in the formation may form fractures in the formation. Thus, controlling the pressure and/or the acidity of water in the formation may control the solubilization of minerals in the formation. In some embodiments, other inorganic acids in the formation enhance the solubilization of minerals such as dolomite.

[1095] In some embodiments, the karsted formation or karsted layers are heated to temperatures above the decomposition temperature of minerals in the formation. At temperatures above the minerals decomposition temperature, the minerals may decompose to produce carbon dioxide or other products. The decomposition of the minerals and the carbon dioxide production may create permeability in the formation and mobilize viscous fluids in the formation. In some embodiments, the produced carbon dioxide is maintained in the formation to generate a gas cap in the formation. The carbon dioxide may be allowed to rise to the upper portions of the karsted layers to generate the gas cap.

[1096] In some embodiments, a formation containing dolomite and hydrocarbons is treated using an in situ heat treatment process. Hydrocarbons may be mobilized and produced from the formation. During treating of a formation containing dolomite, the dolomite may decompose to

form magnesium oxide, carbon dioxide, calcium oxide and water ($MgCO_3 \cdot CaCO_3$) $\rightarrow$ $CaCO_3$ + $MgO + CO_2$). Calcium carbonate may further decompose to calcium oxide and carbon dioxide (CaO and CO_2). During treating, the dolomite may decompose and form intermediate compounds. Upon heating, the intermediate compounds may decompose to form additional magnesium oxide, carbon dioxide and water.

[1097] In certain embodiments, during or after treating a formation with an in situ heat treatment process, carbon dioxide and/or steam is introduced into the formation. The carbon dioxide and/or steam may be introduced at high pressures. The carbon dioxide and/or steam may react with magnesium compounds and calcium compounds in the formation to generate dolomite or other mineral compounds in situ. For example, magnesium carbonate compounds and/or calcium carbonate compounds may be formed in addition to dolomite. Formation conditions may be controlled so that the carbon dioxide, water and magnesium oxide react to form dolomite and/or other mineral compounds. The generated minerals may solidify and form a barrier to a flow of formation fluid into or out of the formation. The generation of dolomite and/or other mineral compounds may allow for economical treatment and/or disposal of carbon dioxide and water produced during treatment of a formation. In some embodiments, carbon dioxide produced from formations may be stored and injected in the formation with steam at high pressure. In some embodiments, the steam includes calcium compounds and/or magnesium compounds.

[1098] In some embodiments, the production front of the drive process follows behind the heat front of the in situ heat treatment process. In some embodiments, areas behind the production front are further heated to produce more fluids from the formation. Further heating behind the production front may also maintain the gas cap behind the production front and/or maintain quality in the production front of the drive process.

[1099] In certain embodiments, the drive process is used before the in situ heat treatment of the formation. In some embodiments, the drive process is used to mobilize fluids in a first section of the formation. The mobilized fluids may then be pushed into a second section by heating the first section with heaters. Fluids may be produced from the second section. In some embodiments, the fluids in the second section are pyrolyzed and/or upgraded using the heaters.

[1100] In formations with low permeabilities, the drive process may be used to create a "gas cushion" or pressure sink before the in situ heat treatment process. The gas cushion may inhibit pressures from increasing quickly to fracture pressure during the in situ heat treatment process. The gas cushion may provide a path for gases to escape or travel during early stages of heating during the in situ heat treatment process.

[1101] In some embodiments, the drive process (for example, the steam injection process) is used to mobilize fluids before the in situ heat treatment process. Steam injection may be used to

get hydrocarbons (oil) away from rock or other strata in the formation. The steam injection may mobilize the oil without significantly heating the rock.

[1102] In some embodiments, injection of a fluid (for example, steam or carbon dioxide) may consume heat in the formation and cool the formation depending on the pressure in the formation. In some embodiments, the injected fluid is used to recover heat from the formation. The recovered heat may be used in surface processing fluids and/or to preheat other portions of the formation using the drive process.

[1103] FIG. 129 depicts an embodiment for heating and producing from the formation with the temperature limited heater in a production wellbore. Production conduit 624 is located in wellbore 490. In certain embodiments, a portion of wellbore 490 is located substantially horizontally in formation 492. In some embodiments, the wellbore is located substantially vertically in the formation. In an embodiment, at least a portion of wellbore 490 is an open wellbore (an uncased wellbore). In some embodiments, the wellbore has a casing or liner with perforations or openings to allow fluid to flow into the wellbore.

[1104] Conduit 624 may be made from carbon steel or more corrosion resistant materials such as stainless steel. Conduit 624 may include apparatus and mechanisms for gas lifting or pumping produced oil to the surface. For example, conduit 624 includes gas lift valves used in a gas lift process. Examples of gas lift control systems and valves are disclosed in U.S. Patent Nos. 6,715,550 to Vinegar et al. and 7,259,688 to Hirsch et al., and U.S. Patent Application Publication No. 2002-0036085 to Bass et al. Conduit 624 may include one or more openings (perforations) to allow fluid to flow into the production conduit. In certain embodiments, the openings in conduit 624 are in a portion of the conduit that remains below the liquid level in wellbore 490. For example, the openings are in a horizontal portion of conduit 624.

[1105] Heater 412 is located in conduit 624. In some embodiments, heater 412 is located outside conduit 624, as shown in FIG. 130. The heater located outside the production conduit may be coupled (strapped) to the production conduit. In some embodiments, more than one heater (for example, two, three, or four heaters) are placed about conduit 624. The use of more than one heater may reduce bowing or flexing of the production conduit caused by heating on only one side of the production conduit. In an embodiment, heater 412 is a temperature limited heater. Heater 412 provides heat to reduce the viscosity of fluid (such as oil or hydrocarbons) in and near wellbore 490. In certain embodiments, heater 412 raises the temperature of the fluid in wellbore 490 up to a temperature of 250 °C or less (for example, 225 °C, 200 °C, or 150 °C). Heater 412 may be at higher temperatures (for example, 275 °C, 300 °C, or 325 °C) because the heater provides heat to conduit 624 and there is some temperature differential between the heater and

the conduit. Thus, heat produced from the heater does not raise the temperature of fluids in the wellbore above 250 °C.

[1106] In certain embodiments, heater 412 includes ferromagnetic materials such as Carpenter Temperature Compensator "32", Alloy 42-6, Alloy 52, Invar 36, or other iron-nickel or iron-nickel-chromium alloys. In certain embodiments, nickel or nickel-chromium alloys are used in heater 412. In some embodiments, heater 412 includes a composite conductor with a more highly conductive material such as copper on the inside of the heater to improve the turndown ratio of the heater. Heat from heater 412 heats fluids in or near wellbore 490 to reduce the viscosity of the fluids and increase a production rate through conduit 624.

[1107] In certain embodiments, portions of heater 412 above the liquid level in wellbore 490 (such as the vertical portion of the wellbore depicted in FIGS. 129 and 130) have a lower maximum temperature than portions of the heater located below the liquid level. For example, portions of heater 412 above the liquid level in wellbore 490 may have a maximum temperature of 100 °C while portions of the heater located below the liquid level have a maximum temperature of 250 °C. In certain embodiments, such a heater includes two or more ferromagnetic sections with different Curie temperatures and/or phase transformation temperature ranges to achieve the desired heating pattern. Providing less heat to portions of wellbore 490 above the liquid level and closer to the surface may save energy.

[1108] In certain embodiments, heater 412 is electrically isolated on the outside surface of the heater and allowed to move freely in conduit 624. In some embodiments, electrically insulating centralizers are placed on the outside of heater 412 to maintain a gap between conduit 624 and the heater.

[1109] In some embodiments, heater 412 is cycled (turned on and off) so that fluids produced through conduit 624 are not overheated. In an embodiment, heater 412 is turned on for a specified amount of time until a temperature of fluids in or near wellbore 490 reaches a desired temperature (for example, the maximum temperature of the heater). During the heating time (for example, 10 days, 20 days, or 30 days), production through conduit 624 may be stopped to allow fluids in the formation to "soak" and obtain a reduced viscosity. After heating is turned off or reduced, production through conduit 624 is started and fluids from the formation are produced without excess heat being provided to the fluids. During production, fluids in or near wellbore 490 will cool down without heat from heater 412 being provided. When the fluids reach a temperature at which production significantly slows down, production is stopped and heater 412 is turned back on to reheat the fluids. This process may be repeated until a desired amount of production is reached. In some embodiments, some heat at a lower temperature is provided to maintain a flow of the produced fluids. For example, low temperature heat (for example, 100 °C,

125 °C, or 150 °C) may be provided in the upper portions of wellbore 490 to keep fluids from cooling to a lower temperature.

[1110] In some embodiments, a temperature limited heater positioned in a wellbore heats steam that is provided to the wellbore. The heated steam may be introduced into a portion of the formation. In certain embodiments, the heated steam may be used as a heat transfer fluid to heat a portion of the formation. In some embodiments, the steam is used to solution mine desired minerals from the formation. In some embodiments, the temperature limited heater positioned in the wellbore heats liquid water that is introduced into a portion of the formation.

[1111] In an embodiment, the temperature limited heater includes ferromagnetic material with a selected Curie temperature and/or a selected phase transformation temperature range. The use of a temperature limited heater may inhibit a temperature of the heater from increasing beyond a maximum selected temperature (for example, a temperature at or about the Curie temperature and/or the phase transformation temperature range). Limiting the temperature of the heater may inhibit potential burnout of the heater. The maximum selected temperature may be a temperature selected to heat the steam to above or near 100% saturation conditions, superheated conditions, or supercritical conditions. Using a temperature limited heater to heat the steam may inhibit overheating of the steam in the wellbore. Steam introduced into a formation may be used for synthesis gas production, to heat the hydrocarbon containing formation, to carry chemicals into the formation, to extract chemicals or minerals from the formation, and/or to control heating of the formation.

[1112] A portion of the formation where steam is introduced or that is heated with steam may be at significant depths below the surface (for example, greater than about 1000 m, about 2500 m, or about 5000 m below the surface). If steam is heated at the surface of the formation and introduced to the formation through a wellbore, a quality of the heated steam provided to the wellbore at the surface may have to be relatively high to accommodate heat losses to the wellbore casing and/or the overburden as the steam travels down the wellbore. Heating the steam in the wellbore may allow the quality of the steam to be significantly improved before the steam is provided to the formation. A temperature limited heater positioned in a lower section of the overburden and/or adjacent to a target zone of the formation may be used to controllably heat steam to improve the quality of the steam injected into the formation and/or inhibit condensation along the length of the heater. In certain embodiments, the temperature limited heater improves the quality of the steam injected and/or inhibits condensation in the wellbore for long steam injection wellbores (especially for long horizontal steam injection wellbores).

[1113] A temperature limited heater positioned in a wellbore may be used to heat the steam to above or near 100% saturation conditions or superheated conditions. In some embodiments, a

temperature limited heater may heat the steam so that the steam is above or near supercritical conditions. The static head of fluid above the temperature limited heater may facilitate producing 100% saturation, superheated, and/or supercritical conditions in the steam. Supercritical or near supercritical steam may be used to strip hydrocarbon material and/or other materials from the formation. In certain embodiments, steam introduced into the formation may have a high density (for example, a specific gravity of about 0.8 or above). Increasing the density of the steam may improve the ability of the steam to strip hydrocarbon material and/or other materials from the formation.

[1114] In some embodiments, the tar sands formation may be treated by the in situ heat treatment process to produce pyrolyzed product from the formation. A significant amount of carbon in the form of coke may remain in tar sands formation when production of pyrolysis product from the formation is complete. In some embodiments, the coke in the formation may be utilized to produce heat and/or additional products from the heated coke containing portions of the formation.

[1115] In some embodiments, air, oxygen enriched air, and/or other oxidants may be introduced into the treatment area that has been pyrolyzed to react with the coke in the treatment area. The temperature of the treatment area may be sufficiently hot to support burning of the coke without additional energy input from heaters. The oxidation of the coke may significantly heat the portion of the formation. Some of the heat may transfer to portions of the formation adjacent to the treatment area. The transferred heat may mobilize fluids in portions of the formation adjacent to the treatment area. The mobilized fluids may flow into and be produced from production wells near the perimeter of the treatment area.

[1116] Gases produced from the formation heated by combusting coke in the formation may be at high temperature. The hot gases may be utilized in an energy recovery cycle (for example, a Kalina cycle or a Rankine cycle) to produce electricity.

[1117] The air, oxygen enriched air and/or other oxidants may be introduced into the formation for a sufficiently long period of time to heat a portion of the treatment area to a desired temperature sufficient to allow for the production of synthesis gas of a desired composition. The temperature may be from 500 °C to about 1000 °C or higher. When the temperature of the portion is at or near the desired temperature, a synthesis gas generating fluid, such as water, may be introduced into the formation to result in the formation of synthesis gas. Synthesis gas produced from the formation may be sent to a treatment facility and/or be sent through a pipeline to a desired location. During introduction of the synthesis gas generating fluid, the introduction of air, oxygen enriched air, and/or other oxidants may be stopped, reduced, or maintained. If the temperature of the formation reduces so that the synthesis gas produced from the formation does

not have the desired composition, introduction of the syntheses gas generating fluid may be stopped or reduced, and the introduction of air, enriched air and/or other oxidants may be started or increased so that oxidation of coke in the formation reheats portions of the treatment area. The introduction of oxidant to heat the formation and the introduction of synthesis gas generating fluid to produce synthesis gas may be cycled until all or a significant portion of the treatment area is treated.

[1118] In certain embodiments, a subsurface formation is treated in stages. The treatment may be initiated with electrical heating with further heating generated from oxidation of hydrocarbons and hot gas production from the formation. Hydrocarbons (for example, heavy hydrocarbons and/or bitumen) may be moved from one portion of the formation to another where the hydrocarbons are produced from the formation. By using a combination of heaters, oxidizing fluid and/or drive fluid, the overall time necessary to initiate production from a formation may be decreased relative to times necessary to initiate production using heaters and/or drive processes alone. By controlling a rate of oxidizing fluid injection and/or drive fluid injection in conjunction with heating with heaters, a relatively uniform temperature distribution may be obtained in sections (portions) of the subsurface formation.

[1119] A method for treating a hydrocarbon containing formation with heaters in combination with an oxidizing fluid may include providing heat to a first portion of the formation from a plurality of heaters located in heater wells in the first portion. Fluids may be produced through one or more production wells in a second portion of the formation that is substantially adjacent to the first portion. The heat provided to the first portion may be reduced or turned off after a selected time. An oxidizing fluid may be provided through one or more of the heater wells in the first portion. Heat may be provided to the first portion and the second portion through oxidation of at least some hydrocarbons in the first portion. Fluids may be produced through at least one of the production wells in the second portion. The fluids may include at least some oxidized hydrocarbons. Transportation fuel may be produced from the hydrocarbons produced from the first and/or second of the formation.

[1120] FIG. 131 depicts a schematic of an embodiment of a first stage of treating the tar sands formation with electrical heaters. Hydrocarbon layer 388 may be separated into section 608A and section 608B. Heaters 412 may be located in section 608A. Production wells 206 may be located in section 608B. In some embodiments, production wells 206 extend into section 608A.

[1121] Heaters 412 may be used to heat and treat portions of section 608A through conductive, convective, and/or radiative heat transfer. For example, heaters 412 may mobilize, visbreak, and/or pyrolyze hydrocarbons in section 608A. Production wells 206 may be used to produce mobilized, visbroken, and/or pyrolyzed hydrocarbons from section 608A.

[1122] FIG. 132 depicts a schematic of an embodiment of a second stage of treating the tar sands formation with fluid injection and oxidation. After at least some hydrocarbons from section 608A have been produced (for example, a majority of hydrocarbons in the section or almost all producible hydrocarbons in the section), the heater wells in section 608A may be converted to injection wells 602. In some embodiments, the heater wells are open wellbores below the overburden. In some embodiments, the heater wells are initially installed into wellbores that include perforated casings. In some embodiments, the heater wells are perforated using perforation guns after heating from the heater wells is completed.

[1123] Injection wells 602 may be used to inject an oxidizing fluid (for example, air, oxygen, enriched air, or other oxidants) into the formation. In some embodiments, the oxidation includes liquid water and/or steam. The amount of oxidizing fluid may be controlled to adjust subsurface combustion patterns. In some embodiments, carbon dioxide or other fluids are injected into the formation to control heating/production in the formation. The oxidizing fluid may oxidize (combust) or otherwise react with hydrocarbons remaining in the formation (for example, coke). Water in the oxidizing fluid may react with coke and/or hydrocarbons in the hot formation to produce syngas in the formation. Production wells 206 in section 608B may be converted to heater/ gas production wells 626. Heater/gas production wells 626 may be used to produce oxidation gases and/or syngas products from the formation. Producing the hot oxidation gases and/or syngas through heater/gas production wells 626 in section 608B may heat the section to higher temperatures so that hydrocarbons in the section are mobilized, visbroken, and/or pyrolyzed in the section. Production wells 206 in section 608C may be used to produce mobilized, visbroken, and/or pyrolyzed hydrocarbons from section 608B.

[1124] In certain embodiments, the pressure of the injected fluids and the pressure in formation are controlled to control the heating in the formation. The pressure in the formation may be controlled by controlling the production rate of fluids from the formation (for example, the production rate of oxidation gases and/or syngas products from heater/gas production wells 626). Heating in the formation may be controlled so that there is enough hydrocarbon volume in the formation to maintain the oxidation reactions in the formation. Heating may be controlled so that the formation near the injection wells is at a temperature that will generate desired synthesis gas if a synthesis gas generating fluid such as water is included in the oxidation fluid. Heating in the formation may also be controlled so that enough heat is generated to conductively heat the formation to mobilize, visbreak, and/or pyrolyze hydrocarbons in adjacent sections of the formation.

[1125] The process of injecting oxidizing fluid and/or water in one section, producing oxidation gases and/or syngas products in an adjacent section to heat the adjacent section, and producing

upgraded hydrocarbons (mobilized, visbroken, and/or pyrolyzed hydrocarbons) from a subsequent section may be continued in further sections of the tar sands formation. For example, FIG. 133 depicts a schematic of an embodiment of a third stage of treating the tar sands formation with fluid injection and oxidation. The gas heater/producer wells in section 608B are converted to injection wells 602 to inject air and/or water. The producer wells in section 608C are converted to production wells (for example, heater/gas production wells 626) to produce oxidation gases and/or syngas products. Production wells 206 are formed in section 608D to produce upgraded hydrocarbons.

[1126] In some embodiments, significant amounts of residue and/or coke remain in a subsurface formation after heating the formation with heaters and producing formation fluids from the formation. In some embodiments, sections of the formation include heavy hydrocarbons such as bitumen that are difficult to heat to mobilization temperatures adjacent to sections of the formation that are being treated using an in situ heat treatment process. Heating of heavy hydrocarbons may require high energy input, a large number of heater wells and/or increase in capital costs (for example, materials for heater construction). It would be advantageous to produce formation fluids from subsurface formations with lower energy costs, fewer heater wells and/or heater cost with improved product quality and/or recovery efficiency.

[1127] In some embodiments, a method for treating a subsurface formation includes producing a at least a third hydrocarbons from a first portion by an in situ heat treatment process. An average temperature of the first portion is less than 350 °C. An oxidizing fluid may be injected in the first portion to cause the average temperature in the first portion to increase sufficiently to oxidize hydrocarbon in the first portion and to raise the average temperature in the first portion to greater than 350 °C. In some embodiments, the temperature of the first portion is raised to an average temperature ranging from 350 °C to 700 °C. A heavy hydrocarbon fluid that includes one or more condensable hydrocarbons may be injected in the first portion to from a diluent and/or drive fluid. In some embodiments, a catalyst system is added to the first portion.

[1128] FIGS. 134, 135, and 136 depict side view representations of embodiments of treating a subsurface formation in stages with heaters, oxidizing fluid, catalyst, and/or drive fluid. Hydrocarbon layer 388 may be divided into three or more treatment sections. In certain embodiments, hydrocarbon layer 388 includes five treatment sections: section 608A, section 608B, section 608C, section 608D and section 608E. Sections 608A and section 608C are separated by section 608B. Sections 608C and section 608E are separated by section 608D. Section 608A through section 608E may be horizontally displaced from each other in the formation. In some embodiments, one side of section 608A is adjacent to an edge of the treatment area of the formation or an untreated section of the formation is left on one side of

section 608A before the same or a different pattern is formed on the opposite side of the untreated section.

[1129] In certain embodiments, section 608A is heated to pyrolysis temperatures with heaters 412. Section 608A may be heated to mobilize and/or pyrolyze hydrocarbons in the section. In some embodiments, section 608A is heated to an average temperature of 250 °C, 300 °C, or up to 350 °C. The mobilized and/or pyrolyzed hydrocarbons may be produced through one or more production wells 206. Once at least a third, a substantial portion, or all of the hydrocarbons have been produced from section 608A, the temperature in section 608A may be maintained at an average temperature that allows the section to be used as a reactor and/or reaction zone to treat formation fluid and/or hydrocarbons from surface facilities. Use of one or more heated portions of the formation to treat such hydrocarbons may reduce or eliminate the need for surface facilities that treat such fluids (for example, coking units and/or delayed coking units).

[1130] In certain embodiments, heating and producing hydrocarbons from sections 608A creates fluid injectivity in the sections. After fluid injectivity has been created in section 608A, an oxidizing fluid may be injected into the section. For example, oxidizing fluid may be injected in section 608A after at least a third or a majority of the hydrocarbons have been produced from the section. The fluid may be injected through heater wellbores, production wells 206, and/or injection wells located in section 608A. In some embodiments, heaters 412 continue to provide heat while the fluid is being injected. In certain embodiments, heaters 412 may be turned down or off before or during fluid injection.

[1131] During injection of oxidant, excess oxidant and/or oxidation products may be removed from section 608A through one or more production wells 206 and/or heater/gas production wells. In some embodiments, after the formation is raised to a desired temperature, a second fluid may be introduced into section 608A. The second fluid may be water and/or steam. Addition of the second fluid may cool the formation. For example, when the second fluid is steam and/or water, the reactions of the second fluid with coke and/or hydrocarbons are endothermic and produce synthesis gas. In some embodiments, oxidizing fluid is added with the second fluid so that some heating of section 608A occurs simultaneous with the endothermic reactions. In some embodiments, section 608A is treated in alternating steps of adding oxidant and second fluid to heat the formation for selected periods of time.

[1132] In certain embodiments, the pressure of the injected fluids and the pressure section 608A are controlled to control the heating in the formation. The pressure in section 608A may be controlled by controlling the production rate of fluids from the section (for example, the production rate of hydrocarbons, oxidation gases and/or syngas products). Heating in section 608A may be controlled so that section reaches a desired temperature (for example, temperatures

of at least 350 °C, of at least about 400 °C, or at least about 500 °C, about 700 °C, or higher). Injection of the oxidizing fluid may allow portions of the formation below the section heated by heaters to be heated, thus allowing heating of formation fluids in deeper and/or inaccessible portions of the formation. The control of heat and pressure in the section may improve efficiency and quality of products produced from the formation.

[1133] During heating and/or after heating of section 608A, heavy hydrocarbons with low economic value and/or waste hydrocarbon streams from surface facilities may be injected in the section. Low economic value hydrocarbons and/or waste hydrocarbon streams may include, but are not limited to, hydrocarbons produced during surface mining operations, residue, bitumen and/or bottom extracts from bitumen mining. In some embodiments, hydrocarbons produced from section 608A or other sections of the formation may be introduced into section 608A. In some embodiments, one or more of the heater wells in section 608A are converted to injection wells.

[1134] Heating of hydrocarbons and/or coke in section 608A may generate drive fluids. Generated drive fluids in section 608A may include air, steam, carbon dioxide, carbon monoxide, hydrogen, methane, pyrolyzed hydrocarbons and/or in situ diluent. In some embodiments, hydrocarbon fluids are introduced into section 608A prior to injecting an oxidizing fluid and/or the second fluid. Oxidation and/or thermal cracking of introduced hydrocarbon fluids may create the drive fluid.

[1135] In some embodiments, drive fluid may be injected into the formation. The addition of oxidizing fluid, steam, and/or water in the drive fluid may be used to control temperatures in section 608A. For example, the addition of hydrocarbons to section 608A may cool the average temperature in section 608A to a temperature below temperatures that allow for cracking of the introduced hydrocarbons. Oxidizing fluid may be injected to increase and/or maintain the average temperature between 250 °C and 700 °C or between 350 °C and 600 °C. Maintaining the temperature between 250 °C and 700 °C may allow for the production of high quality hydrocarbons from the low value hydrocarbons and/or waste streams. Controlling the input of hydrocarbons, oxidizing fluid, and/or drive fluid into section 608A may allow for the production of condensable hydrocarbons with a minimal amount non-condensable gases. In some embodiments, controlling the input of hydrocarbons, oxidizing fluid, and/or drive fluid into section 608A may allow for the production of large amounts of non-condensable hydrocarbons and/or hydrogen with minimal amounts of condensable hydrocarbons.

[1136] In some embodiments, a catalyst system is introduced to section 608A when the section is at a desired temperature (for example, a temperature of at least 350 °C, at least 400 °C, or at least 500 °C). In some embodiments, the section is heated after and/or during introduction of the

catalyst system. The catalyst system may be provided to the formation by injecting the catalyst system into one or more injection wells and/or production wells in section 608A. In some embodiments, the catalyst system is positioned in wellbores proximate the section of the formation to be treated. In some embodiments, the catalyst is introduced to one or more sections during in situ heat treatment of the sections. The catalyst may be provided to section 608A as a slurry and/or a solution in sufficient quantity to allow the catalyst to be dispersed in the section. For example, the catalyst system may be dissolved in water and/or slurried in an emulsion of water and hydrocarbons. At temperatures of at least 100 °C, at least 200 °C, or at least 250 °C, vaporization of water from the solution allows the catalyst to be dispersed in the rock matrix of section 608A.

[1137] The catalyst system may include one or more catalysts. The catalysts may be supported or unsupported catalysts. Catalysts include, but are not limited to, alkali metal carbonates, alkali metal hydroxides, alkali metal hydrides, alkali metal amides, alkali metal sulfides, alkali metal acetates, alkali metal oxalates, alkali metal formates, alkali metal pyruvates, alkaline-earth metal carbonates, alkaline-earth metal hydroxides, alkaline-earth metal hydrides, alkaline-earth metal amides, alkaline-earth metal sulfides, alkaline-earth metal acetates, alkaline-earth metal oxalates, alkaline-earth metal formates, alkaline-earth metal pyruvates, or commercially available fluid catalytic cracking catalysts, dolomite, silicon-alumina catalyst fines, zeolites, zeolite catalyst fines any catalyst that promotes formation of aromatic hydrocarbons, or mixtures thereof.

[1138] In some embodiments, fractions from surface facilities include catalyst fines. Surface facilities may include catalytic cracking units and/or hydrotreating units. These fractions may be injected in section 608A to provide a source of catalyst for the section. Injection of the fractions in section 608A may provide an advantageous method for disposal and/or upgrading of the fractions as compared to conventional disposal methods for fractions containing catalyst fines.

[1139] After injecting catalyst in section 608A, the average temperature in section 608A may be increased or maintained in a range from about 250 °C to about 700 °C, from about 300 °C to about 650°C, or from about 350 °C to about 600 °C by injection of reaction fluids (for example, oxidizing fluid, steam, water and/or combinations thereof). In some embodiments, heaters 412 are used to raise or maintain the temperature in section 608A in the desired range. In some embodiments, heaters 412 and the introduction of reaction fluids into section 608A are used to raise or maintain the temperature in the desired range. Hydrocarbon fluids may be introduced in section 608A once the desired temperature is obtained. In some embodiments, the catalyst system is slurried with a portion of the hydrocarbons, and the slurry is introduced to section 608A. In some embodiments, a portion of the hydrocarbon fluids are introduced to section 608A prior to introduction of the catalyst system. The introduced hydrocarbon fluids may be

hydrocarbons in formation fluid from an adjacent portion of the formation, and/or low value hydrocarbons. The hydrocarbons may contact the catalyst system to produce desirable hydrocarbons (for example, visbroken hydrocarbons, cracked hydrocarbons, aromatic hydrocarbons, or mixtures thereof). The desired temperature in section 608A may be maintained by turning on heaters in the section and/or continuous injection of oxidizing fluid to cause exothermic reactions that heat the formation.

[1140] In some embodiments, hydrocarbons produced through thermal and/or catalytic treatment in section 608A may be used as a diluent and/or a solvent in the section. The produced hydrocarbons may include aromatic hydrocarbons. The aromatic enriched diluent may dilute or solubilize a portion of the heavy hydrocarbons in section 608A and/or other sections in the formation (for example, sections 608B and/or 608C) and form a mixture. The mixture may be produced from the formation (for example, produced from sections 608A and/or 608C). In some embodiments, the mixture is produced from section 608B. In some embodiments, the mixture drains to a bottom portion of the section and solubilizes additional hydrocarbons at the bottom of the section. Solubilized hydrocarbons may be produced or mobilized from the formation. In some embodiments, fluids produced in section 608A (for example, diluent, desirable products, oxidized products, and/or solubilized hydrocarbons) may be pushed towards section 608B as shown by the arrows in FIG. 134 by oxidizing fluid, drive fluid, and/or created drive fluid.

[1141] In some embodiments, the temperatures in section 608A and the generation of drive fluid in section 608A increases the pressure of section 608A so the drive fluid pushes fluids through section 608B into section 608C. Hot fluids flowing from section 608A into section 608B may melt, solubilize, visbreak and/or crack fluids in section 608B sufficiently to allow the fluids to move to section 608C. In section 608C, the fluids may be upgraded and/or produced through production wells 206.

[1142] In some embodiments, a portion of the catalyst system from section 608A enters section 608B and/or section 608C and contacts fluids in the sections. Contact of the catalyst with formation fluids in 608B and/or section 608C may result in the production of hydrocarbons having a lower API gravity than the mobilized fluids.

[1143] The fluid mixture formed from contact of hydrocarbons, formation fluid and/or mobilized fluids with the catalyst system may be produced from the formation. The liquid hydrocarbon portion of the fluid mixture may have an API gravity between 10° and 25°, between 12° and 23° or between 15° and 20°. In some embodiments, the produced mixture has at most 0.25 grams of aromatics per gram of total hydrocarbons. In some embodiments, the produced mixture includes some of the catalysts and/or used catalysts.

[1144] In some embodiments, contact of the hydrocarbon fluids with the catalyst system produces coke in 608A. Oxidizing fluid may be introduced into section 608A. The oxidizing fluid may react with the coke to generate heat that maintains the average temperature of section 608A in a desired range. For some time intervals, additional oxidizing fluid may be added to section 608A to increase the oxidation reactions to regenerate catalyst in the section. The reaction of the oxidizing fluid with the coke may reduce the amount of coke and heat formation and/or catalyst to temperatures sufficient to remove impurities on the catalyst. Coke, nitrogen containing compounds, sulfur containing compounds, and/or metals such as nickel and/or vanadium may be removed from the catalyst. Removing impurities from the catalyst in situ may enhance catalyst life. After catalyst regeneration, introduction of reaction fluids may be adjusted to allow section 608A to return to an average temperature in the desired temperature range. The average temperature in section 608A may the controlled to be in range from about 250 °C to about 700 °C. Hydrocarbons may be introduced in section 608A to continue the cycle. Additional catalyst systems may be introduced into the formation as needed.

[1145] A method for treating a subsurface formation in stages may include using an in situ heat treatment process in combination with injection of an oxidizing fluid and/or drive fluid in one or more portions (sections) of the formation. In some embodiments, hydrocarbons are produced from a first portion and/or a third portion by an in situ heat treatment process. A second portion that separates the first and third portions may be heated with one or more heaters to an average temperature of at least about 100 °C. The heat provided to the first portion may be reduced or turned off after a selected time. Oxidizing fluid may be injected in the first portion to oxidize hydrocarbons in the first portion and raise the temperature of the first portion. A drive fluid and/or additional oxidizing fluid may be injected and/or created in the third portion to cause at least some hydrocarbons to move from the third portion through the second portion to the first portion of the hydrocarbon layer. Injection of the oxidizing fluid in the first portion may be reduced or discontinued and additional hydrocarbons and/or syngas may be produced from the first portion of the formation. The additional hydrocarbons and/or syngas may include at least some hydrocarbons from the second and third portions of the formation. Transportation fuel may be produced from the hydrocarbons produced from the first, second and/or third portions of the formation. In some embodiments, a catalyst system is provided to the first portion and/or third portion.

[1146] In certain embodiments, sections 608A and 608C are heated at or near the same time to similar temperatures (for example, pyrolysis temperatures) with heaters 412. Sections 608A and 608C may be heated to mobilize and/or pyrolyze hydrocarbons in the sections. The mobilized and/or pyrolyzed hydrocarbons may be produced (for example, through one or more production

wells 206) from section 608A and/or section 608C. Section 608B may be heated to lower temperatures (for example, mobilization temperatures) by heaters 412. Sections 608D and 608E may not be heated. Little or no production of hydrocarbons to the surface may take place through section 608B, section 608D and/or section 608E. For example, sections 608A and 608C may be heated to average temperatures of at least about 300 °C or at least about 330 °C while section 608B is heated to an average temperature of at least about 100 °C, sections 608D and 608E are not heated and no production wells are operated in section 608B, section 608D, and/or section 608E. In some embodiments, heat from section 608A and/or section 608C transfers to sections section 608D and/or section 608E.

[1147] In some embodiments, heavy hydrocarbons in section 608B may be heated to mobilization temperatures and flow into sections 608A and 608C. The mobilized hydrocarbons may be produce from production wells 206 in sections 608A and 608C. After some or most of the fluids have been produced from sections 608A and 608C, production of formation fluids in the sections may be slowed and/or discontinued.

[1148] In certain embodiments, heating and producing hydrocarbons from sections 608A and 608C creates fluid injectivity in the sections. After fluid injectivity has been created in section 608C, an oxidizing fluid may be injected into the section. For example, oxidizing fluid may be injected in section 608C after a majority of the hydrocarbons have been produced from the section. The fluid may be injected through heaters 412, production wells 206, and/or injection wells located in section 608C. In some embodiments, heaters 412 continue to provide heat while the fluid is being injected. In certain embodiments, heaters 412 may be turned down or off before or during fluid injection.

[1149] During injection of oxidant, excess oxidant and/or oxidation products may be removed from section 608C through one or more production wells 206 and/or heater/gas production wells. In some embodiments, after the formation is raised to a desired temperature, a second fluid may be introduced into section 608C. The second fluid may be steam and/or water. Addition of the second fluid may cool the formation. For example, when the second fluid is steam and/or water, the reactions of the second fluid with coke and/or hydrocarbons are endothermic and produce synthesis gas. In some embodiments, oxidizing fluid is added with the second fluid so that some heating of section 608C occurs simultaneous with the endothermic reactions. In some embodiments, section 608C is treated in alternating steps of adding oxidant and second fluid to heat the formation for selected periods of time.

[1150] In certain embodiments, the pressure of the injected fluids and the pressure section 608C are controlled to control the heating in the formation. The pressure in section 608C may be controlled by controlling the production rate of fluids from the section (for example, the

production rate of hydrocarbons, oxidation gases and/or syngas products). Heating in section 608C may be controlled so that there is enough hydrocarbon volume in the section to maintain the oxidation reactions in the formation. Heating and/or pressure in section 608C may also be controlled (for example, by producing a minimal amount of hydrocarbons, oxidation gases and/or syngas products) so that enough pressure is generated to create fractures in sections adjacent to the section (for example, creation of fractures in section 608B). Creation of fractures in adjacent sections may allow fluids from adjacent sections to flow into section 608C and cool the section. Injection of oxidizing fluid may allow portions of the formation below the section heated by heaters to be heated, thus allowing heating of formation fluids in deeper and/or inaccessible portions of the subsurface to be accessed. Section 608C may be cooled from temperatures that promote syngas production to temperatures that promote formation of visbroken and/or upgrade products. Such control of heat and pressure in the section may improve efficiency and quality of products produced from the formation.

[1151] During heating of section 608C or after the section has reached a desired temperature (for example, temperatures of at least 300 °C, at least about 400 °C, or at least about 500 °C), an oxidizing fluid and/or a drive fluid may be injected and/or created in section 608A. The drive fluid includes, but is not limited to, steam, water, hydrocarbons, surfactants, polymers, carbon dioxide, air, or mixtures thereof. In some embodiments, the catalyst system described herein is injected in section 608A. In some embodiments, the catalyst system is injected prior to injecting the oxidizing fluid. In some embodiments, production of fluid from section 608A is discontinued prior to injecting fluids in the section. In some embodiments, heater wells in section 608A are converted to injection wells.

[1152] In some embodiments, drive fluids are created in section 608A. Created drive fluids may include air, steam, carbon dioxide, carbon monoxide, hydrogen, methane, pyrolyzed hydrocarbons and/or diluent. In some embodiments, hydrocarbons (for example, hydrocarbons produced from section 608A and/or section 608C, low value hydrocarbons and/or or waste hydrocarbon streams) are provided as a portion of the drive fluid. In some embodiments, hydrocarbons are introduced into section 608A prior to injecting an oxidizing fluid and/or the second fluid. Oxidation, catalytic cracking, and/or thermal cracking of introduced hydrocarbon fluids may create the drive fluid and/or a diluent.

[1153] In some embodiments, oxidizing fluid, steam or water are provided as a portion of the drive fluid. The addition of oxidizing fluid, steam, and/or water in the drive fluid may be used to control temperatures in the sections. For example, the addition of steam or water may be cool the section. In some embodiments, water injected as the drive fluid is turned into steam in the formation due to the higher temperatures in the formation. The conversion of water to steam

may be used to reduce temperatures or maintain temperatures in the sections between 270 °C and 450°C. Maintaining the temperature between 270 °C and 450°C may produce higher quality hydrocarbons and/or generate a minimal amount of non-condensable gases.

[1154] Residual hydrocarbons and/or coke in section 608A may be melted, visbroken, upgraded and/or oxidized to produce products that may be pushed towards section 608B as shown by the arrows in FIG. 134. In some embodiments, the temperature in section 608C and the generation of drive fluid in section 608A may increase the pressure of section 608A so the drive fluid pushes fluids through section 608B into section 608C. Hot fluids flowing from section 608A into section 608B may melt and/or visbreak fluids in section 608B sufficiently to allow the fluids to move to section 608C. In section 608C, the fluids may be upgraded and/or produced through production wells 206.

[1155] In some embodiments, oxidizing fluid injected in section 608A is controlled to raise the average temperature in the section to a desired temperature (for example, at least about 350 °C, or at least about 450 °C). Injection of oxidizing fluid and/or drive fluid in section 608A may continue until most or a substantial portion of the fluids from section 608A are moved through section 608B to section 608C. After a period of time, injection of oxidant and/or drive fluid into 608A is slowed and/or discontinued.

[1156] Injection of oxidizing fluid into section 608C may be slowed or stopped during injection and/or creation of drive fluid and/or creation of diluent in section 608A. In some embodiments, injection of oxidizing fluid in section 608C is continued to maintain an average temperature in the section of about 500 °C during injection and/or creation of drive fluid and/or diluent in section 608A. In some embodiments, the catalyst system is injected in section 608C.

[1157] As section 608A and/or section 608C are treated with oxidizing fluid, heaters in sections 608D and 608E may be turned on. In some embodiments, section 608D is heated through conductive heat transfer from section 608C and/or convective heat transfer. Section 608E may be heated with heaters. For example, an average temperature in section 608E may be raised to above 300 °C while an average temperature in section 608D is maintained between 80 °C and 120 °C (for example, at about 100 °C).

[1158] As temperatures in section 608E reach a desired temperature (for example, above 300 °C), production of formation fluids from section 608E through production wells 206 may be started. The temperature may be reached before, during or after oxidizing fluid and/or drive fluid is injected and/or drive fluid and/or diluent is created in section 608A.

[1159] Once the desired temperature in section 608E has been obtained (for example, above 300 °C, or above 400 °C), production may be slowed and/or stopped in section 608C and oxidation fluid and/or drive fluid is injected and/or created in section 608C to move fluids from section

608C through cooler section 608D towards section 608E as shown by the arrows in FIG. 135. Injection and/or creation of additional oxidation fluid and/or drive fluid in section 608C may upgrade hydrocarbons from section 608B that are in section 608C and/or may move fluids towards section 608E.

[1160] In some embodiments, heaters in combination with heating produced by oxidizing hydrocarbons in sections 608A, 608C and/or section 608E allows for a reduction in the number of heaters to be used in the sections and/or less capital costs as heaters made of less expensive materials may be used. The heating pattern may be repeated through the formation.

[1161] In some embodiments, fluids in hydrocarbon layer 388 (for example, layers in a tar sands formation) may preferentially move horizontally within the hydrocarbon layer from the point of injection because the layers tend to have a larger horizontal permeability than vertical permeability. The higher horizontal permeability allows the injected fluid to move hydrocarbons between sections preferentially versus fluids draining vertically due to gravity in the formation. Providing sufficient fluid pressure with the injected fluid may ensure that fluids are moved from section 608A through section 608B into section 608C for upgrading and/or production or from section 608C through section 608D into section 608E for upgrading and/or production. Increased heating in sections 608A, 608C, and 608E may mobilize fluids from sections 608B and 608D into adjacent sections. Increased heating may also mobilize fluids below section 608A through 608E and the fluid may flow from the colder sections into the heated sections for upgrading and/or production due to pressure gradients established by producing fluid from the formation. In some embodiments, one or more production wells are placed in the formation below sections 608A through 608E to facilitate production of additional hydrocarbons.

[1162] In some embodiments, after sections 608A and 608C are heated to desired temperatures, the oxidizing fluid is injected into section 608C to increase the temperature in the section. The fluids in section 608C may move through section 608B into section 608A as indicated by the arrows in FIG. 136. The fluids may be produced from section 608A. Once a majority of the fluids have been produced from section 608A, the treatment process described in FIG. 134 and FIG. 135 may be repeated.

[1163] In some embodiments, treating a formation in stages includes heating a first portion from one or more heaters located in the first portion. Hydrocarbons may be produced from the first portion. Heat provided to the first portion may be reduced or turned off after a selected time. A second portion may be substantially adjacent to the first portion. An oxidizing fluid may be injected in the first portion to cause a temperature of the first portion to increase sufficiently to oxidize hydrocarbons in the first portion and a third portion, the third portion being substantially below the first portion. The second portion may be heated from heat provided from the first

portion and/or third portion and/or one or more heaters located in the second portion such that an average temperature in the second portion is at least about 100 °C. Hydrocarbons may flow from the second portion into the first portion and/or third portion. Injection of the oxidizing fluid may be reduced or discontinued in the first portion. The temperature of the first portion may cool to below 600 °C to 700 °C and additional hydrocarbons may be produced from the first portion of the formation. The additional hydrocarbons may include oxidized hydrocarbons from the first portion, at least some hydrocarbons from the second portion, at least some hydrocarbons from the third portion of the formation, or mixtures thereof. Transportation fuel may be produced from the hydrocarbons produced from the first, second and/or third portions of the formation.

[1164] In some embodiments, in situ heat treatment followed by oxidation and/or catalyst addition as described for horizontal sections is performed in vertical sections of the formation. Heating a bottom vertical layer followed by oxidation may create microfractures in middle sections thus allowing heavy hydrocarbons to flow from the "cold" middle section to the warmer bottom section. Lighter fluids may flow into the top section and continue to be upgraded and/or produced through production wells. In some embodiments, two vertical sections are treated with heaters followed by oxidizing fluid.

[1165] In some embodiments, heaters in combination with an oxidizing fluid and/or drive fluid are used in various patterns. For example, cylindrical patterns, square patterns, or hexagonal patterns may be used to heat and produce fluids from a subsurface formation. FIG. 137 and FIG. 138, depict various patterns for treatment of a subsurface formation. FIG. 137 depicts an embodiment of treating a subsurface formation using a cylindrical pattern. FIG. 138 depicts an embodiment of treating multiple sections of a subsurface formation in a rectangular pattern. FIG. 139 is a schematic top view of the pattern depicted in FIG. 138.

[1166] Hydrocarbon layer 388 may be separated into section 608A and section 608B. Section 608A represents a section of the subsurface formation that is to be produced using an in situ heat treatment process. Section 608B represents a section of formation that surrounds section 608A and is not heated during the in situ heat treatment process. In certain embodiments, section 608B has a larger volume than section 608A and/or section 608C. Section 608A may be heated using heaters 412 to mobilize and/or pyrolyze hydrocarbons in the section. The mobilized and/or pyrolyzed hydrocarbons may be produced (for example, through one or more production wells 206) from section 608A. After some or all of the hydrocarbons in section 608A have been produced, an oxidizing fluid may be injected into the section. The fluid may be injected through heaters 412, a production well, and/or an injection well located in section 608A. In some embodiments, at least a portion of heaters 412 are used and/or converted to injection wells. In

some embodiments, heaters 412 continue to provide heat while the fluid is being injected. In other embodiments, heaters 412 may be turned down or off before or during fluid injection.

[1167] In some embodiments, providing oxidizing fluid such as air to section 608A causes oxidation of hydrocarbons in the section and in portions of section 608C. In some embodiments, treatment of section 608A with the heaters creates coked hydrocarbons and formation with substantially uniform porosity and/or substantially uniform injectivity so that heating of the section is controllable when oxidizing fluid is introduced to the section. The oxidation of hydrocarbons in section 608A will maintain the average temperature of the section or increase the average temperature of the section to higher temperatures (for example, above 400 °C, above 500 °C, above 600 °C, or higher).

[1168] In some embodiments, an average temperature of section 608C that is located below section 608A increases due to heat generated through oxidation of hydrocarbons and/or coke in section 608A. For example, an average temperature in section 608C may increase from formation temperature to above 500 °C. As the average temperature in section 608A and/or section 608C increases through oxidation reactions, the temperature in section 608B increases and fluids may be mobilized towards section 608A as shown by the arrows in FIG. 137 and FIG. 138. In some embodiments, section 608B is heated by heaters to an average temperature of at least about 100 °C.

[1169] In section 608A, mobilized hydrocarbons are oxidized and/or pyrolyzed to produce visbroken, oxidized, pyrolyzed products. For example, cold bitumen in section 608B may be heated to mobilization temperature of at least about 100 °C so that it flows into section 608A and/or section 608C. In section 608A and/or section 608C, the bitumen is pyrolyzed to produce formation fluids. Fluids may be produced through production wells 206 and/or heater/gas production wells in section 608A. In some embodiments, no fluids are produced from section 608A during oxidation. Injection of oxidizing fluid may be reduced or discontinued in section 608A once a desired temperature is reached (for example, a temperature of at least 350 °C, at least 300 °C, or above 450 °C). Once oxidizing fluid is slowed and/or discontinued in sections 608A, 608C, the sections may cool (for example, to temperatures below about 700 °C, about 600 °C, below 500 °C or below 400 °C) and remain at upgrading and/or pyrolysis temperatures for a period of time. Fluids may continue to be upgraded and may be produced from section 608A through production wells.

[1170] In certain embodiments, section 608B and/or section 608D as described in reference to FIGS. 131-139 has a larger volume than section 608A, section 608C, and/or section 608E. Section 608B and/or section 608D may be larger in volume than the other sections so that more hydrocarbons are produced for less energy input into the formation. Because less heat is

provided to section 608B and/or section 608D (the section is heated to lower temperatures), having a larger volume in section 608B and/or section 608D reduces the total energy input to the formation per unit volume. The desired volume of section 608B and/or section 608D may depend on factors such as, but not limited to, viscosity, oil saturation, and permeability. In addition, the degree of coking is much less in section 608B and/or section 608D due to the lower temperature so less hydrocarbons are coked in the formation when section 608B and/or section 608D has a larger volume. In some embodiments, the lower degree of heating in section 608B and/or section 608D allows for cheaper capital costs as lower temperature materials (cheaper materials) may be used for heaters used in section 608B and/or section 608D.

[1171] Using the remaining hydrocarbons for heat generation and only using electrical heating for the initial heating stage may improve the overall energy use efficiency of treating the formation. Using electrical heating only in the initial step may decrease the electrical power needs for treating the formation. In addition, forming wells that are used for the combination of production, injection, and heating/gas production may decrease well construction costs. In some embodiments, hot gases produced from the formation are provided to turbines. Providing the hot gases to turbines may recover some energy and improve the overall energy use efficiency of the process used to treat the formation.

[1172] Treating the subsurface formation, as shown by the embodiments of FIGS. 131 - 137 may utilize carbon remaining after production of mobilized, visbroken, and/or pyrolyzed hydrocarbons for heat generation in the formation. In some embodiment, treating hydrocarbons in the subsurface formation, as shown in by the embodiments in FIGS. 131-137 creates products having economic value from hydrocarbons having low economic value and/or from waste hydrocarbon streams from surface facilities.

[1173] In some embodiments, a drive process (or steam injection, for example, SAGD, cyclic steam soak, or another steam recovery process) and/or in situ heat treatment process are used to treat the formation and produce hydrocarbons from the formation. Treating the formation using the drive process and/or in situ heat treatment process may not treat the formation uniformly. Variations in the properties of the formation (for example, fluid injectivities, permeabilities, and/or porosities) may result in insufficient heat to raise the temperature of one or more portions of the formation to mobilize hydrocarbons due to channeling of the heat (for example, channeling of steam) in the formation. In some embodiments, the formation has portions that have been heated to a temperature of at most 200 °C or at most 100 °C. After the drive process and/or in situ heat treatment process is completed, the formation may have portions that have lower amounts of hydrocarbons produced (more hydrocarbons remaining) than other parts of the formation.

[1174] In some embodiments, a formation that has been previously treated may be assessed to determine one or more portions of the formation that have not been heated to a sufficient temperature using a drive process and/or an in situ heat treatment process. Coring, logging techniques, and/or seismic imaging may be used to assess hydrocarbons remaining in the formation and assess the location of one or more of the untreated portions. The untreated portions may contain at least 50%, at least 60%, at least 80% or at least 90% of the initial hydrocarbons. In some embodiments, the portions with more hydrocarbons remaining are large portions of the formation. In some embodiments, the amount of hydrocarbons remaining in untreated portions is significantly higher than treated portions of the formation. For example, an untreated portion may have a recovery of at most about 10% of the hydrocarbons in place and a treated portion may have a recovery of at least about 50% of the hydrocarbons in place.

[1175] In some embodiments, heaters are placed in the untreated portions to provide heat to the portion. Heat from the heaters may raise the temperature in the untreated portion to an average temperature of at least about 200 °C to mobilize hydrocarbons in the untreated portion.

[1176] In certain embodiments, a drive fluid may be injected in the untreated portion after the average temperature of the portion has been raised using an in situ heat treatment process. Injection of a drive fluid may mobilize hydrocarbons in the untreated portion toward one or more productions wells in the formation. In some embodiments, the drive fluid is injected in the untreated portion to raise the temperature of the portion.

[1177] FIGS. 140 and 141 depict side view representations of embodiments of treating a tar sands formation after treatment of the formation using a steam injection process and/or an in situ heat treatment process. Hydrocarbon layer 388 may have been previously treated using a steam injection process and/or an in situ heat treatment process. Portion 1412 of hydrocarbon layer 388 may have had measurable amounts of hydrocarbons removed by a steam injection process and/or an in situ heat treatment process. Portions 1414 in hydrocarbon layer 388 may have been near treated portions (for example, portion 1412) however, an average temperature in portions 1414 was not sufficient to heat the portions and mobilize hydrocarbons in the portions. Thus, portion 1414 remains untreated and may have a greater amount of hydrocarbons remaining than portions 1412 following treatment with the steam injection process and/or an in situ heat treatment process. In some embodiments, hydrocarbon layer 388 includes two or more portions 1414 with more hydrocarbons remaining than portions 1412.

[1178] Heaters 412 may be placed in untreated portions 1414 to provide additional heat to these portions. Heat from heaters 412 may raise an average temperature in portions 1414 to mobilized hydrocarbons in the portions. Hydrocarbons mobilized from portions 1414 may be produced from the production well 206.

[1179] In some embodiments, a drive fluid is provided to untreated portions 1414 after heating with heaters 412. As shown in FIG. 141, injection well 602 is used to inject a drive fluid (for example, steam and/or hot carbon dioxide) into hydrocarbon layer 388 below overburden 400. The drive fluid moves mobilized hydrocarbons in portions 1414 towards production well 206. In some embodiments, the drive fluid is provided to untreated portions 1414 prior to heating with heaters 412 and/or heaters 412 are not necessary.

[1180] In some embodiments, formation fluid produced from hydrocarbon containing formations using an in situ heat treatment process may have an API gravity of at least 20°, at least 25°, at least 30°, at least 35° or at least 40°. In certain embodiments, the in situ heat treatment process provides substantially uniform heating of the hydrocarbon containing formation. Due to the substantially uniform heating the formation fluid produced from a hydrocarbon containing formation may contain lower amounts of halogenated compounds (for example, chlorides and fluorides) arsenic or compounds of arsenic, ammonium carbonate and/or ammonium bicarbonate as compared to formation fluids produced from conventional processing (for example, surface retorting or subsurface retorting). The produced formation fluid may contain non-hydrocarbon gases, hydrocarbons, or mixtures thereof. The hydrocarbons may have a carbon number ranging from 5 to 30.

[1181] Hydrocarbon containing formations (for example, oil shale formations and/or tar sands formations) may contain significant amounts of bitumen entrained in the mineral matrix of the formation and/or a significant amounts of bitumen in shallow layers of the formation. Heating hydrocarbon formations containing entrained bitumen to high temperatures may produce of non-condensable hydrocarbons and non-hydrocarbon gases instead of liquid hydrocarbons and/or bitumen. Heating shallow formation layers containing bitumen may also result in a significant amount of gaseous products produced from the formation. Methods and/or systems of heating hydrocarbon formations having entrained bitumen at lower temperatures that convert portions of the formation to bitumen and/or lower molecular weight hydrocarbons and/or increases permeability in the hydrocarbon containing formation to produce liquid hydrocarbons and/or bitumen are desired.

[1182] In some embodiments, an oil shale formation is heated using an in situ heat treatment process using a plurality of heaters. Heat from the heaters is allowed to heat portions of the oil shale formation to an average temperature that allows conversion of at least a portion of kerogen in the formation to bitumen, other hydrocarbons. Heating of the formation may create permeability in the oil shale to mobilize the bitumen and/or other hydrocarbons entrained in the kerogen. The oil shale formation may include at least 20%, at least 30% or at least 50% bitumen. The oil shale formation may be heated to an average temperature ranging from about 250°C to

about 350°C, from about 260°C to about 340 °C, or from about 270°C to about 330°C. Heating at temperatures at or below pyrolysis temperatures may inhibit production of hydrocarbon gases and/or non-hydrocarbon gases, convert portions of the kerogen to bitumen and/or increase permeability in the mineral matrix such that the bitumen is released from the mineral matrix. The bitumen may be mobilized towards production wells and produced through production wells and/or heater wells in the oil shale formation. The produced bitumen may be processed to produce commercial products.

[1183] In some embodiments, production rates from two or more production wells located in a treatment area of a hydrocarbon containing formation are controlled to produce bitumen and/or liquid hydrocarbons having selected qualities. In some embodiments, the hydrocarbon containing formation is an oil shale formation. Selective control of operating conditions (for example, heating rate, average temperatures in the formation, and production rates) may allow production of bitumen from a first production well located in the first portion of the hydrocarbon containing formation and production of liquid hydrocarbons from one or more second production wells located in another portion of the hydrocarbon containing formation. In some embodiments, the liquid hydrocarbons produced from the second production wells contain none or substantially no bitumen. Selected qualities of the liquid hydrocarbons include, but are not limited to, boiling point distribution and/or API gravity. Production of bitumen using the methods described herein from a first production well while producing mobilized and/or visbroken hydrocarbons from second production wells in a portion of the hydrocarbon formation that is at a lower temperature than other portions may inhibit coking in the second production wells. Furthermore, quality of the mobilized and/or visbroken hydrocarbons produced from the second production wells is of higher quality relative to producing hydrocarbons from a single production well since all or most of the bitumen is produced from the first production well.

[1184] In some embodiments, heat provided from heaters to the first portion of the hydrocarbon formation may be sufficient to pyrolyze hydrocarbons and/or kerogen to form an in situ drive fluid (for example, pyrolyzation fluids that contain a significant amount of gases or vaporized liquids) near heaters positioned in the first portion of the formation. In some embodiments, the heaters may be positioned around the production wells in the first portion. Pyrolysis of kerogen, bitumen and/or hydrocarbons may produce carbon dioxide, C_1-C_4 hydrocarbons, and/or hydrogen. Pressure in one or more heater wellbores in the first portion may be controlled (for example, increased) such that the in situ drive fluid moves bitumen towards one or more production wells in the first portion. Bitumen may be produced from one or more productions wells in the first portion of the formation. In some embodiments, the production wells are heater

wells and/or contain heaters. Providing heat to a production well or producing through a heater well may inhibit the bitumen from solidifying during production.

[1185] Bitumen produced from oil shale formations may have more hydrogen, more straight chain hydrocarbons, more hydrocarbons that contain heteroatoms (for example, sulfur, oxygen and/or nitrogen atoms), less metals and be more viscous than bitumen produced from a tar sands formation. Since the bitumen produced from an oil shale formation may be different from bitumen produced from a tar sands formation, the products produced from oil shale bitumen may have different and/or better properties than products produced from tar sands bitumen. In some embodiments, hydrocarbons separated from bitumen produced from an oil shale formation has a boiling range distribution between 343 °C and 538 °C at 0.101 MPa, a low metal content and/or a high nitrogen content which makes the hydrocarbons suitable for use as feed for refinery processes (for example, feed for a catalytic and/or thermal cracking unit to produce naphtha). VGO made from bitumen produced from oil shale may have more hydrogen relative to heavy oil used in conventional processing. Other products (for example, organic sulfur compounds, organic oxygen compounds and/or organic sulfur compounds) separated from oil shale bitumen may have commercial value or be used as solvation fluids during an in situ heat treatment process.

[1186] FIGS. 142 and 143 depict a top view representation of embodiments of treatment of a hydrocarbon containing formation using an in situ heat treatment process. In some embodiments, the hydrocarbon containing formation is in an oil shale formation. Heaters 412 may be may be positioned in heater wells in portions of hydrocarbon layer 388 between first production well 206A and second productions wells 206B. Heaters 412 may surround first production well 206A. In some embodiments, heaters 412 and/or production wells 206A, 206B may be positioned substantially vertical hydrocarbon layer 388. Patterns of heater wells, such as triangles, squares, rectangles, hexagons and/or octagons may be used. In certain embodiments, portions of hydrocarbon layer 388 that include heaters 412 and production wells 206 may be surrounded by one or more perimeter barriers, either naturally occurring (for example, overburden and/or underburden) or installed (for example, barrier wells). Selective amounts of heat may be provided to portions of the treatment area as a function of the quality of formation fluid to be produced from the first and/or second production wells. Amounts of heat may be provided by varying the number and/or density of heaters in the portions. The number and spacing of heaters may be adjusted to obtain the formation fluid with the desired qualities from first production well 206A and second production wells 206B. In some embodiments, heaters 412 are spaced about 1.5 m from first production well 206A.

[1187] Heaters 412 provide heat to a first portion of hydrocarbon layer 388 between heaters 412 and first production well 206A. An average temperature in the first portion between heaters 412 and production well 206A may range from about 200 °C to about 250 °C or from about 220°C to about 240°C. The mobilized bitumen may be produced from production well 206A. In some embodiments, production well 206A is a heater well. In some embodiments, bitumen is produced from heaters 412 surrounding production well 206A.

[1188] The produced bitumen may be treated at facilities at the production site and/or transported to other treatment facilities. In some embodiments, the temperature and pressure in the portion between heaters 412 and production well 206A is sufficient to allow bitumen entrained in the kerogen to flow out of the kerogen and move towards first production well 206A. The temperature and pressure in first production well 206A may be controlled to reduce the viscosity of the bitumen to allow the bitumen to be produced as a liquid.

[1189] Heat provided from heaters 412 may heat a second portion of hydrocarbon layer 388 proximate heaters 412 to an average temperature ranging from 250 °C to about 300 °C or from about 270 °C to about 280 °C. The average temperature in the second portion proximate heaters 412 may be sufficient to pyrolyze kerogen, visbreak bitumen and/or mobilize hydrocarbons in the portion to generate formation fluid. The generated formation fluid may include some gaseous hydrocarbons, liquid mobilized, visbroken, and/or pyrolyzed hydrocarbons and/or bitumen. Maintaining the average temperature in the second portion proximate heaters 412 in a range from 250 °C to about 280°C may promote production of liquid hydrocarbons and bitumen instead of production of hydrocarbon gases near the heaters.

[1190] The pressure in portions of hydrocarbon layer 388 may be controlled to be below the lithostatic pressure of the portions near the heaters and/or production wells. The average temperature and pressure may be controlled in the portions proximate the heaters and/or production wells such that the permeability of the portions is substantially uniform. A substantially uniform permeability may inhibit channeling of the formation fluid through the portions. Having a substantially uniform permeable portion may inhibit channeling of the bitumen, mobilized hydrocarbons and/or visbroken hydrocarbons in the portion.

[1191] At least some of the formation fluid generated proximate heaters 412 may move towards second production wells 206B positioned in a third portion of hydrocarbon layer 388. Mobilized and/or visbroken hydrocarbon may be produced from second production wells 206B. Average temperatures in the third portion of hydrocarbon layer 388 proximate second production wells 206B may be less than average temperatures in the second portions near heaters 412 and/or the first portion between heaters 412 and first production wells 206A. In some embodiments, mobilized and/or visbroken hydrocarbons are cold produced from second production wells 206B.

Temperature and pressure in the third portions proximate second production wells 206B may be controlled to produce mobilized and/or visbroken hydrocarbons having selected properties. In certain embodiments, hydrocarbons produced from second production wells 206B may contain a minimal amount of bitumen or hydrocarbons having a boiling point greater than 538°C. The hydrocarbons produced from production wells 206B may have an API gravity of at least 35°. In some embodiments, a majority of the hydrocarbons produced from second production wells 206B have a boiling range distribution between 343 °C and 538 °C at 0.101 MPa.

[1192] Producing mobilized and/or visbroken hydrocarbons from second production wells 206B in the third portion at a lower temperature than the first and/or second portions may inhibit coking in the second production wells and/or improve product quality of the produced mobilized and/or visbroken liquid hydrocarbons.

[1193] In some embodiments, a drive fluid is injected and/or created in the hydrocarbon containing formation to allow mobilization of bitumen and/or heavier hydrocarbons in the formation towards first production well 206A. The drive fluid may include formation fluid recovered and/or generated from the in situ heat treatment process. For example, the drive fluid may include, but is not limited to, carbon dioxide, C1-C7 hydrocarbons and/or steam recovered and/or generated from pyrolysis of hydrocarbons from the in situ heat treatment of the oil shale formation.

[1194] In some embodiments, heat provided to portions between heaters 412 and first production well 206A is sufficient to pyrolyze hydrocarbons and/or kerogen and generate the drive fluid in situ (for example, pyrolyzation fluids that are gases). Pressure in one or more heater wellbores may be controlled such that in situ drive fluid moves bitumen between second production wells 206B and first production well 206A towards the first production well 206A as shown by arrows 1416 in FIG. 143. In some embodiments, the in situ drive fluid creates a barrier (gas cap) in the portion between heaters 412 and second production wells 206B to inhibit bitumen or heavy hydrocarbons from migrating towards the second production wells, thus allowing higher quality liquid hydrocarbons to be produced from second production wells 206B.

[1195] In some embodiments, the drive fluid and/or solvation fluid is injected in hydrocarbon layer 388 through second production wells 206B, heaters 412, or one or more injection wells 602 (shown in FIG. 143), and move bitumen in portions between second production wells 206B and first production well 206A towards the first production well. In some embodiments, the pressure in one or more of the wellbores is increased by introducing the drive fluid through the wellbore under pressure such that the drive fluid drives at least a portion of the bitumen towards first production well 206A. In some embodiments, an average temperature of the portion of the formation the solvation fluid is injected ranges from about 200 °C to about 300 °C. The average

temperature in the portion between heaters 412 and first production well 206A may be sufficient to pyrolyze kerogen, and/or thermally visbreak at least some the bitumen and/or solvation fluid as it moves through the portion. The driven fluid and/or solvated fluid may be cooled as it is moves towards first production well 206A. Cooling of the fluid as it approaches first production well 206A may inhibit coking of fluids in or proximate the first production well. Bitumen and/or heavy hydrocarbons containing bitumen from portions between second production wells 206B and first production well 206A may be produced from first production well 206A. In some embodiments, the formation fluid produced from first production well 206A includes solvation fluid and/or drive fluid.

[1196] In some embodiments, hydrocarbons containing heteroatoms (for example, nitrogen, sulfur and/or oxygen) are separated from the produced bitumen and used as a solvation fluid. Production and recycling of a solvation fluid containing heteroatoms may remove unwanted compounds from the bitumen. In some embodiments, organic nitrogen compounds produced from the in situ conversion process is used as a solvation fluid. The organic nitrogen compounds may be injected into a formation having a high concentration of sulfur containing compounds. The organic nitrogen compounds may react and/or complex with the sulfur or sulfur compounds and form compounds that have chemical characteristics that facilitate removal of the sulfur from the formation fluid.

[1197] In certain embodiments, high molecular organonitrogen compounds may be used as solvation fluids. The high molecular weight organonitrogen compounds may be produced from an in situ heat treatment process, injected in the formation, produced from the formation and re-injected in the formation. Heating of the high molecular weight organonitrogen compounds in the formation may reduce the molecular weight of the organonitrogen compounds and form lower molecular weight organonitrogen compounds. Formation of lower molecular weight organonitrogen compounds may facilitate removal of nitrogen compounds from liquid hydrocarbons and/or formation fluid in surface treatment facilities.

[1198] Treating hydrocarbon containing formations in order to convert, upgrade, and/or extract the hydrocarbons is an expensive and time consuming process. Any process and/or system which might increase the efficiency of the treatment of the formation is highly desirable. Increasing the efficiency of the treatment of the formation may include optimizing heat source locations and the spacing between the heat sources in a pattern of heat sources. Increasing the efficiency of the treatment of the formation may include optimizing the heating schedule of the formation. Repositioning the location of a producer well (for example, vertically within the formation) may increase the efficiency of the treatment of the formation. Adjusting the initial bottom-hole pressure of one or more producer well in the formation may increase the efficiency

of the formation treatment process. Adjusting the blowdown time of one or more producer wells may increase the efficiency of the formation treatment process. Optimizing one or more of the mentioned variables alone, or in combination, may increase the efficiency of the formation treatment process resulting in reduced costs and/or increased production. Even a relatively small increase of efficiency may result in billions of dollars of additional revenue due to the scale of such treatment processes in the form of reduced operating costs, increased quality of the hydrocarbon product produced, and/or increased quantity of the hydrocarbon product produced from the formation.

[1199] Many different types of wells or wellbores may be used to treat the hydrocarbon containing formation using the in situ heat treatment process. In some embodiments, vertical and/or substantially vertical wells are used to treat the formation. In some embodiments, horizontal (such as J-shaped wells and/or L-shaped wells), and/or u-shaped wells are used to treat the formation. In some embodiments, combinations of horizontal wells, vertical wells, and/or other combinations are used to treat the formation. In certain embodiments, wells extend through the overburden of the formation to a hydrocarbon containing layer of the formation. Heat in the wells may be lost to the overburden. In certain embodiments, surface and/or overburden infrastructures used to support heaters and/or production equipment in horizontal wellbores and/or u-shaped wellbores are large in size and/or numerous.

[1200] In certain embodiments, heaters, heater power sources, production equipment, supply lines, and/or other heater or production support equipment are positioned in substantially horizontal and/or inclined tunnels. Positioning these structures in tunnels may allow smaller sized heaters and/or other equipment to be used to treat the formation. Positioning these structures in tunnels may also reduce energy costs for treating the formation, reduce emissions from the treatment process, facilitate heating system installation, and/or reduce heat loss to the overburden, as compared to conventional hydrocarbon recovery processes that utilize surface based equipment. U.S. Published Patent Application Nos. 2007-0044957 to Watson et al.; 2008-0017416 to Watson et al.; and 2008-0078552 to Donnelly et al., all of which are incorporated herein by reference, describe methods of drilling from a shaft for underground recovery of hydrocarbons and methods of underground recovery of hydrocarbons.

[1201] In some embodiments, increasing the efficiency of the treatment of the formation may include optimizing heat source locations and the spacing between the heat sources in a pattern of heat sources. In certain embodiments, heat sources (for example, heaters) have uneven or irregular spacing in a heater pattern. For example, the space between heat sources in the heater pattern varies or the heat sources are not evenly distributed in the heater pattern. In certain embodiments, the space between heat sources in the heater pattern decreases as the distance from

the production well at the center of the pattern increases. Thus, the density of heat sources (number of heat sources per square area) increases as the heat sources get more distant from the production well.

[1202] In some embodiments, heat sources are evenly spaced in the heater pattern but have varying heat outputs such that the heat sources provide an uneven or varying heat distribution in the heater pattern. Varying the heat output of the heat sources may be used to, for example, effectively mimic having heat sources with varying spacing in the heater pattern. For example, heat sources closer to the production well at the center of the heater pattern may provide lower heat outputs than heat sources at further distances from the production well. The heater outputs may be varied such that the heater outputs gradually increase as the heat sources increase in distance from the production well.

[1203] Heat sources may be positioned in an irregular pattern in a horizontally oriented heating zone of the formation in relation to, for example, a producer well. Heat sources may be positioned in an irregular pattern in a vertically oriented heating zone of the formation in relation to, for example, a producer well. Irregular patterns may have advantages over previous equivalently spaced patterns relative to a producer well. For example, irregular patterns of heat sources may create channels within the formation to assist in directing hydrocarbons through the channels more efficiently to producer wells. In some embodiments, patterns of heat sources may be based on the distribution and/or type of hydrocarbons in the formation. The portion of the formation may be divided into different heating zones. Different zones within the same formation may have different patterns of heaters within each zone, for example, depending upon the particular type of hydrocarbon within the particular heating zone.

[1204] Using irregular patterns for positioning heat sources in the formation may reduce the number of heat sources needed in the formation. The installation and maintenance of heat sources in a formation accounts for a significant percentage of the operating costs associated with the treatment of the formation. In some instances, installation and maintenance of heat sources in the formation may account for as much as 40%, 50%, 60%, or more of the operating costs of treating the formation. Reducing the number of heaters used to treat the formation has significant economic benefits. Reducing the time that heaters are used to heat the portion of the formation will reduce costs associated with treating the portion.

[1205] In certain embodiments, the uneven or irregular spacing of heat sources is based on regular geometric patterns. For example, the irregular spacing of heat sources may be based on a hexagonal, triangular, square, octagonal, other geometric combinations, and/or combinations thereof. In some embodiments, heat sources are placed at irregular intervals along one or more of the geometric patterns to provide the irregular spacing. In some embodiments, the heat

sources are placed in an irregular geometric pattern. In some embodiments, the geometric pattern has irregular spacing between rows in the pattern to provide the irregular spacing of heat sources.

[1206] Increasing the efficiency of the treatment of the formation may include optimizing the heating schedule of the formation. As previously mentioned, the installation and maintenance of heat sources in a formation accounts for a significant percentage of the operating costs associated with the treatment of the formation. Maintenance may include the energy required by the heat sources to heat the formation. Previously, treatment of a portion of a formation included heating the formation with heat sources, the majority of which were typically turned on at the same time or at least within a relatively short time frame. In some embodiments, implementing a heating schedule may include heating the portion of the formation in phases. Different horizontal zones within the portion of the formation may be controlled independently and may be heated at different times during the treatment process. Different vertical zones within the portion of the formation may be controlled independently and may be heated at different times during the treatment process. Heat sources within different zones within a portion may start their heating cycle at different times.

[1207] Heating in a first zone of the formation may be initiated using a first set of heat sources positioned in the first zone. Heating in a second zone of the formation may be initiated using a second set of heat sources positioned in the second zone. Heating may be initiated in the second zone after the first set of heat sources in the first zone have commenced heating the first zone. Heating in the first zone may continue after heating in the second zone initiates. In some embodiments, heating in the first zone may discontinue when, or at some point after, heating in the second zone initiates. When referring to the first zone or the second zone herein, this nomenclature should not be seen as limiting and these terms do not refer to the physical relation of the different zones to each other within the portion of the formation. In some embodiments, the portion of the formation may include two or more heating zones. For example, the portion of the formation may include 3, 4, 5, or 6 heating zones per portion of the formation. In certain embodiments, the portion of the formation includes 4 heating zones per portion of the formation. The heating zone may include one or more rows of heat sources. In some embodiments, heat produced by heat sources within different heating zones overlaps providing a cumulative heating effect upon the portion of the formation where the overlap occurs. Different portions of the formation may have different heat source patterns and/or numbers of heat sources within each zone.

[1208] In some embodiments, heater sequencing is used to increase efficiency by heating a bottom portion of the formation before heating an upper portion of the formation. Heating the bottom portion of the formation first may allow some in situ conversion of any hydrocarbons (for

example, bitumen) in the bottom portion. As hydrocarbons products are produced from the bottom portion using production wells positioned in the formation, hydrocarbons from the upper portion of the formation may be conveyed towards the bottom portion. In some embodiments, hydrocarbons from the upper portion that have been conveyed to the lower portion have not been heated by heat sources positioned in the upper portion.

[1209] In some embodiments, the lower portion of the formation includes approximately the lower third of the formation (not including the overburden). The upper portion may include approximately the upper two thirds of the formation (not including the overburden). In certain embodiments, about 20% or more heat flux per volume is injected into the lower portion than the upper portion over the first five years of treatment of the formation. For the entire formation, such injection may equate into about 15% less heat flux per volume for the first five years as compared to turning on all of the heaters at the same time using heaters with consistent heater spacing.

[1210] Greater heat flux per volume may be provided to one portion (for example, the lower portion) relative to another portion (for example, the upper portion) of the formation using several different methods. In some embodiments, the lower portion includes more heat sources than the upper portion. In some embodiments, heat sources in the lower portion provide heat for a longer period of time than heat sources in the upper portion of the formation. In some embodiments, heat sources in the lower portion provide more energy per heat source than heat sources in the upper portion. Any combination of the mentioned methods may be used to ensure greater heat flux to one portion of the formation relative to another portion of the formation.

[1211] Producing hydrocarbons from the lower portion first may create space in the lower formation for hydrocarbons from the upper portion to be conveyed by gravity to the lower portion. Not heating hydrocarbons in the upper portion of the formation may reduce over cracking or over pyrolyzing of these hydrocarbons, which may result in a better quality of produced hydrocarbons for the formation. Using such a strategy may result in a lower gas to oil ratio. In some embodiments, a greater reduction in the percentage of gas produced relative to the increase in the percentage of oil produced may result, but the overall total market value of the products may be greater.

[1212] In certain embodiments, hydrocarbons in the lower portion are pyrolyzed and produced first, and any pyrolyzation products (for example, gas products) resulting from the pyrolyzation process in the lower portion may move out of the lower portion into the upper portion. Products moving from the lower portion to the upper portion of the formation may result in temperature increasing in the upper portion. Temperature increases in the upper portion may result in increased mobility in the upper portion resulting in easier movement of hydrocarbons in the

upper portion to the lower portion for pyrolyzation and/or production. Pyrolyzation products moving to the upper portion may result in pressure increasing in the upper portion, which may drive hydrocarbons to the lower portion for pyrolyzation and/or production.

[1213] In certain embodiments, production wells are positioned in and/or substantially adjacent a lower portion of the formation. Positioning production wells in and/or substantially adjacent a lower portion of the formation facilitates production of hydrocarbons from the lower portion of the formation. Heat sources adjacent to the production well may be horizontally and/or vertically offset from the production well. In some embodiments, a horizontal row of heat sources is positioned at a depth equivalent to the depth of the production well. A row of multiple heat sources may also be positioned at a greater or lesser depth than the depth of the production well. Such an arrangement of heat sources relative to the production well may create channels within the formation for movement of mobilized and/or pyrolyzed hydrocarbons toward the production well.

[1214] FIG. 144 depicts a cross-sectional representation of substantially horizontal heaters 412 positioned in a pattern with consistent spacing in a hydrocarbon layer in the Grosmont formation. Horizontal heaters 412 are positioned in a consistently spaced pattern around and in relation to producer wells 206 in hydrocarbon layer 388 beneath overburden 400. Patterns with consistent spacing, typically horizontally and vertically, as depicted in FIG. 144 have been discussed previously. FIG. 145 depicts a cross-sectional representation of substantially horizontal heaters 412 positioned in a pattern with irregular spacing in hydrocarbon layer 388 in the Grosmont formation. Horizontal heaters 412 are positioned in an irregularly spaced pattern around and in relation to producer wells 206 in hydrocarbon layer 388 beneath overburden 400. In the embodiment depicted in FIG. 144, there are 16 horizontal heaters 412 per producer well 206. The pattern depicted in FIG. 145 includes four rows of heaters in four heating zones 628A-D. In the embodiment depicted in FIG. 145, vertical spacing between the different rows of heaters in heating zones 628A-D is irregular. There may be at least some to significant overlap of the heat between the rows of heaters. For example, heaters 412 in zones 628C-D may both heat the area of the formation positioned substantially between the two rows of heaters. In the embodiment depicted in FIG. 145, there are 18 horizontal heaters 412 per producer well 206.

[1215] Heaters 412 in the FIG. 144 embodiment may initiate heating the formation substantially within the same time frame. Heaters 412 in the FIG. 145 embodiment may employ a phased heating process for heating the formation. Heaters 412 in zones 628C-D may initiate first, heating the formation at the same time. Heaters 412 in zone 628B may initiate at a later date (for example, ~104 days after the heaters in zones 628C-D), and finally followed by heaters 412 in zone 628A (for example, ~593 days after the heaters in zones 628C-D).

[1216] FIG. 146 depicts a graphical representation of a comparison of the temperature and the pressure over time for two different portions of the formation using the different heating patterns. Curve 630 depicts the average temperature and curve 632 the average pressure during the treatment process using the consistently spaced heater pattern depicted in FIG. 144. Curve 634 depicts the average temperature and curve 636 the average pressure during the treatment process using the optimized heater pattern depicted in FIG. 145. FIG. 146 shows that average temperature and pressure are lower for the portion of the formation using the optimized heater pattern. The lower average temperature and pressure for the portion of the formation using the optimized heater pattern may explain the increased quality of oil produced by this portion.

[1217] FIG. 147 depicts a graphical representation of a comparison of the average temperature over time for different treatment areas for two different portions of the formation using the different heating patterns. Curves 638, 642, and 646 show the average temperature over time for the Upper Grosmont 3, the Upper Ireton, and Nisku areas, respectively, of the portion of the formation during the treatment process using the consistently spaced heater pattern depicted in FIG. 144. Curves 640, 644, and 648 show the average temperature over time for the Upper Grosmont 3, the Upper Ireton, and Nisku areas, respectively, of the portion of the formation during the treatment process using the optimized heater pattern depicted in FIG. 145. A lower average temperature is seen in FIG. 147 for the optimized heater pattern for the deeper Upper Grosmont 3 and Upper Ireton; however, the Nisku which is heated directly in the optimized heater pattern has a higher average temperature.

[1218] In the embodiment depicted in FIG. 144, the bottom-hole pressure was overall kept at a relatively high pressure, which varied greatly over the course of the treatment process. Additionally, the blowdown time was at greater than 2000 days and the upper layer of the hydrocarbon containing portion below the overburden was not heated for the embodiment depicted in FIG. 144. However, for the embodiment depicted in FIG. 145, the bottom-hole pressure was overall kept at a relatively low pressure which varied little for long periods of time over the course of the treatment process. The blowdown time was at ~400 days and the upper layer of the hydrocarbon containing portion below the overburden was heated (see the heaters in zone 628A) for the embodiment depicted in FIG. 145. In some embodiments, the pressure in the formation is increased to between about 2070 kPa (about 300 psi) and about 3450 kPa (about 500 psi) for a period of time. The period of time may be 200 days to 600 days, 300 days to 500 days, or 350 days to 450 days. After the period of time has expired, the pressure in the formation may be decreased to between about 515 kPa (about 75 psi) and about 1030 kPa (about 150 psi), between about 500 kPa and about 1000 kPa, or between about 450 kPa and about 1100 kPa. FIG. 148 depicts a graphical representation of the bottom-hole pressures over time for two

producer wells (curves 650 and 652) associated with the heater pattern in FIG. 144 and for two producer wells (curves 654 and 656) associated with the heater pattern in FIG. 145. Some of the differences between the two treatment processes are summarized in TABLE 2.

TABLE 2

	Heater Pattern in FIG. 144	Heater Pattern in FIG. 145
Number of Heaters/Producer	16	18
Heating Schedule	Constant heating of entire portion of formation	Phased heating
Blowdown Time	Late (>2000 days)	Early (<600 days)
Bottom-Hole Pressure	High and variable	Low and steady
Heater Spacing	Consistent spacing	Variable horizontal and vertical spacing
Upper Area of Treated Portion	No direct heat	Directly heated with installed heaters

[1219] The differences between the heating process depicted in FIG. 144 and in FIG. 145 resulted in significant differences in the results of the treatment processes. In the optimized heating treatment process, depicted in FIG. 145, a preferably much lower gas-to-oil ratio (GOR) resulted relative to the treatment process depicted in FIG. 144. Heating in zone 628A increased liquid hydrocarbon production by ~38% in the zone relative to a similar area in the treatment process depicted in FIG. 144. In addition, overall oil production was increased and the bitumen fraction decreased for the optimized heating treatment process FIG. 145 relative to the FIG. 144 treatment process.

[1220] FIG. 149 depicts a graphical representation of a comparison of the cumulative oil and gas products extracted over time from two different portions of the formation using the different heating patterns. Curves 658 and 662 show the cumulative oil and gas products, respectively, extracted over time for the portion of the formation using the consistently spaced heater pattern depicted in FIG. 144. Curves 660 and 664 show the cumulative oil and gas products, respectively, extracted over time for the portion of the formation using the optimized heater pattern depicted in FIG. 145. The optimized heater pattern produced significantly more oil, but less gas, due to the lower operating temperatures and less pyrolyzation of the hydrocarbons. Some of the differences between the results of using the two treatment processes are summarized in TABLE 3. In TABLE 3, only the percent change for NPV (net present value), NPV/Capital Expenses, and NPV/(Capital Expenses + Operating Expenses) are shown.

TABLE 3

	Heater Pattern in FIG. 144	Heater Pattern in FIG. 145	Percent Change

Cumulative Oil (bbl)	58,891	78,746	33.7%
Cumulative Resid (bbl)	16,802	17,771	5.8%
Cumulative distillate (bbl)	41,314	60,456	46.2%
Cumulative Gas (MMscf)	104.0	69.5	-33.2%
Cumulative Heat (MMBTU)	80,715	77,577	-3.9%
Heat Efficiency (bbl/MMBTU)	0.73	1.02	39.7%
API	22.9	24.6	7.4%
NPV			40.9%
NPV/Capital Expenses			26.2%
NPV/(Capital Expenses + Operating Expenses)			39.0%

[1221] FIG. 150 depicts a cross-sectional representation of another embodiment of substantially horizontal heaters 412 positioned in a pattern with irregular spacing in hydrocarbon layer 388 in the Grosmont formation. Horizontal heaters 412 are positioned in an irregularly spaced pattern around and in relation to producer wells 206 beneath overburden 400. The pattern depicted in FIG. 150 includes five rows of heaters in five heating zones 628A-E. In the embodiment depicted in FIG. 150, vertical spacing between the different rows of heaters in heating zones 628A-E is irregular. There may be at least some to significant overlap of the heat between the rows of heaters. For example, heaters 412 in zones 628C-E may both heat the area of the formation positioned substantially between the three rows of heaters. In the embodiment depicted in FIG. 150, there are 18 horizontal heaters 412 per producer well 206 as in the irregularly spaced four row heater pattern depicted in FIG. 145.

[1222] Heaters 412 in the FIG. 150 embodiment may employ a phased heating process for heating the formation similar to the embodiment depicted in FIG. 145. Heaters 412 in zone 628E may initiate first. Heaters 412 in zone 628D may initiate at a later date (for example, ~5 days after the heaters in zone 628E), followed by heaters 412 in zone 628C (for example, ~57 days after the heaters in zone 628E). Heaters 412 in zone 628B may initiate at a later date (for example, ~391 days after the heaters in zone 628E), finally followed by heaters 412 in zone 628A (for example, ~547 days after the heaters in zone 628E).

[1223] FIG. 151 depicts a cross-sectional representation of yet another embodiment of substantially horizontal heaters 412 positioned in a pattern with irregular spacing in hydrocarbon layer 388. In an embodiment, the hydrocarbon layer is a portion of the Grosmont formation. The pattern depicted in FIG. 151 includes four rows of heaters in four heating zones 628A-D. In the

embodiment depicted in FIG. 151, vertical spacing between the different rows of heaters in heating zones 628A-D is irregular. In the embodiment depicted in FIG. 151, there are 17 horizontal heaters 412 per producer well 206.

[1224] Heaters 412 in the FIG. 151 embodiment may employ a phased heating process for heating the formation similar to the embodiment depicted in FIG. 145. Heaters 412 in zones 628C-D may initiate first. Heaters 412 in zone 628B may initiate at a later date (for example, ~17 days after the heaters in zones 628C-D), followed by heaters 412 in zone 628A (for example, ~411 days after the heaters in zones 628C-D).

[1225] FIG. 152 depicts a cross-sectional representation of another additional embodiment of substantially horizontal heaters 412 positioned in a pattern with irregular spacing in hydrocarbon layer 388 in the Grosmont formation. The pattern depicted in FIG. 152 includes four rows of heaters in four heating zones 628A-D. In the embodiment depicted in FIG. 152, vertical spacing between the different rows of heaters in heating zones 628A-D is irregular. In the embodiment depicted in FIG. 152, there are 15 horizontal heaters 412 per producer well 206.

[1226] Heaters 412 in the FIG. 152 embodiment may employ a phased heating process for heating the formation, similar to the embodiment depicted in FIG. 145. Heaters 412 in zones 628C-D may initiate first. Heaters 412 in zone 628B may initiate at a later date (for example, ~46 days after the heaters in zones 628C-D), followed by heaters 412 in zone 628A (for example, ~291 days after the heaters in zones 628C-D). A comparison of some of the results of the different optimized heating patterns are summarized in TABLE 4. TABLE 4 shows that different patterns of heaters have real impact on the overall efficiency and profitability of the treatment process for subsurface hydrocarbon containing formations. In TABLE 4, Capital Expenses, NPV (net present value), NPV/Capital Expenses, IRR (internal rate of return), and NPV/(Capital Expenses + Operating Expenses) are scaled to percentages of values for the heater pattern depicted in FIG. 145. As shown in TABLE 4, using fewer heaters does not necessarily lead to the most desirable result. In certain embodiments, the most efficient heater pattern for certain formations appears to be the heater pattern depicted in FIG. 145.

TABLE 4

	Heater Pattern in FIG. 145	Heater Pattern in FIG. 150	Heater Pattern in FIG. 151	Heater Pattern in FIG. 152
No. of Heaters/ Producer	18	18	17	15
Capital Expenses	100%	100%	94.7%	84.4%
NPV	2.17	91.2%	87.5%	77.4%
NPV/Capital Expenses	5.64	91.3%	94.0%	91.8%
IRR	0.67	89.5%	94.0%	100%

Max. Pressure	471.3	608.69	686.3	572.2
Cum. Oil (bbl)	78,745.9	71,107.9	67,551.48	60,132.5
API	24.6	27.94	23.16	21.6
NPV/(Capital Expenses + Operating Expenses)	1.64	91.5%	93.9%	91.5%

[1227] FIG. 153 depicts a cross-sectional representation of another embodiment of substantially horizontal heaters 412 positioned in a pattern with consistent spacing in hydrocarbon layer 388 (similar to the heater pattern in 144) in the Peace River formation. In the embodiment depicted in FIG. 153, there are 9 horizontal heaters 412 per producer well 206. FIG. 154 depicts a cross-sectional representation of an embodiment of substantially horizontal heaters 412 positioned in a pattern with irregular spacing in hydrocarbon layer 388, with three rows of heaters in three heating zones 628A-C. In the embodiment depicted in FIG. 154, vertical spacing between the different rows of heaters in heating zones 628A-C is irregular. In the embodiment depicted in FIG. 154, there are 13 horizontal heaters 412 per producer well 206.

[1228] Heaters 412 in the embodiment depicted in FIG. 154 may employ a phased heating process for heating in the Peace River formation that is similar to phased heating process for the embodiment depicted in FIG. 145 in the Grosmont formation. Heaters 412 in zone 628C may initiate first. Heaters 412 in zone 628A may initiate at a later date (for example, ~53 days after the heaters in zone 628C), followed by heaters 412 in zone 628B (for example, ~93 days after the heaters in zone 628C). The optimized heating pattern depicted in FIG. 154 demonstrated greater efficiency than the heating pattern depicted in FIG. 153 (relative NPV was 5.3:1 for FIG. 154: FIG. 153).

[1229] In some embodiments, when optimizing the heating of the portion of the formation, certain limiting variables are taken into consideration. The pressure in the upper area of the portion of the formation may be limited. Imposing limits on the pressure in the upper portion of the formation may inhibit the overburden from pyrolyzation and allowing products from the treatment process to escape in an uncontrolled manner. Pressure in the upper area of the portion limited to less than or equal to about 1500 psi (about 10 MPa), about 1250 psi (about 8.6 MPa), about 1000 psi (about 6.9 MPa), about 750 psi (about 5.2 MPa), or about 500 psi (about 3.4 MPa). In some embodiments, pressure in the upper area of the portion of the formation may be maintained at about 750 psi (about 5.2 MPa) or less.

[1230] In some embodiments, bottom-hole pressure may need to be maintained greater than or equal to a particular pressure. Bottom-hole pressure, in some examples, may need to be maintained during production at or above about 250 psi (about 1.7 MPa), about 170 psi (about 1.2 MPa), about 115 psi (about 800 kPa), or about 70 psi (about 480 kPa). In some

embodiments, a desired bottom-hole pressure may be maintained at or above about 115 psi (about 800 kPa). The minimum bottom-hole pressure required may be dependent on a number of factors, for example, type of formation or the type of hydrocarbons contained in the formation.

[1231] A downhole heater assembly may include 5, 10, 20, 40, or more heaters coupled together. For example, a heater assembly may include between 10 and 40 heaters. Heaters in a downhole heater assembly may be coupled in series. In some embodiments, heaters in a heater assembly may be spaced from about 8 meters (about 25 feet) to about 60 meters (about 195 feet) apart. For example, heaters in a heater assembly may be spaced about 15 meters (about 50 feet) apart. Spacing between heaters in a heater assembly may be a function of heat transfer from the heaters to the formation. Spacing between heaters may be chosen to limit temperature variation along a length of a heater assembly to acceptable limits. Heaters in a heater assembly may include, but are not limited to, electrical heaters, flameless distributed combustors, natural distributed combustors, and/or oxidizers. In some embodiments, heaters in a downhole heater assembly may include only oxidizers.

[1232] Fuel may be supplied to oxidizers a fuel conduit. In some embodiments, the fuel for the oxidizers includes synthesis gas, non-condensable gases produced from treatment area of in situ heat treatment processes, air, enriched air, or mixtures thereof. In some embodiments, the fuel includes synthesis gas (for example, a mixture that includes hydrogen and carbon monoxide) that was produced using an in situ heat treatment process. In certain embodiments, the fuel may include natural gas mixed with heavier components such as ethane, propane, butane, or carbon monoxide. In some embodiments, the fuel and/or synthesis gas may include non-combustible gases such as nitrogen. In some embodiments, the fuel contains products from a coal or heavy oil gasification process. The coal or heavy oil gasification process may be an in situ process or an ex situ process. After initiation of combustion of fuel and oxidant mixture in oxidizers, composition of the fuel may be varied to enhance operational stability of the oxidizers.

[1233] The non-condensable gases may include combustible gases (for example, hydrogen, hydrogen sulfide, methane and other hydrocarbon gases) and noncombustible gases (for example, carbon dioxide). The presence of noncombustible gases may inhibit coking of the fuel and/or may reduce the flame zone temperature of oxidizers when the fuel is used as fuel for oxidizers of downhole oxidizer assemblies. The reduced flame zone temperature may inhibit formation of NOx compounds and/or other undesired combustion products by the oxidizers. Other components such as water may be included in the fuel supplied to the burners. Combustion of in situ heat treatment process gas may reduce and/or eliminate the need for gas treatment facilities and/or the need to treat the non-condensable portion of formation fluid produced using the in situ heat treatment process to obtain pipeline gas and/or other gas products. Combustion of in situ

heat treatment process gas in burners may create concentrated carbon dioxide and/or SO_x effluents that may be used in other processes, sequestered and/or treated to remove undesired components.

[1234] In certain embodiments, fuel used to initiate combustion may be enriched to decrease the temperature required for ignition or otherwise facilitate startup of oxidizers. In some embodiments, hydrogen or other hydrogen rich fluids may be used to enrich fuel initially supplied to the oxidizers. After ignition of the oxidizers, enrichment of the fuel may be stopped. In some embodiments, a portion or portions of a fuel conduit may include a catalytic surface (for example, a catalytic outer surface) to decrease an ignition temperature of fuel.

[1235] In some embodiments, oxygen is produced through the decomposition of water. For example, electrolysis of water produces oxygen and hydrogen. Using water as a source of oxygen provides a source of oxidant with minimal or no carbon dioxide emissions. The produced hydrogen may be used as a hydrogenation fluid for treating hydrocarbon fluids in situ or ex situ, a fuel source and/or for other purposes. FIG. 155 depicts a schematic representation of an embodiment of a system for producing oxygen using electrolysis of water for use in an oxidizing fluid provided to burners that heat treatment area 666. Water stream 668 enters electrolysis unit 670. In electrolysis unit 670, current is applied to water stream 668 and produces oxygen stream 672 and hydrogen stream 674. In some embodiments, electrolysis of water stream 668 is performed at temperatures ranging from about 600 °C to about 1000 °C, from about 700 °C to about 950 °C, or from 800 °C to about 900 °C. In some embodiments, electrolysis unit 670 is powered by nuclear energy and/or a solid oxide fuel cell and/or a molten salt fuel cell. The use of nuclear energy and/or a solid oxide fuel cell and/or a molten salt fuel cell provides a heat source with minimal and/or no carbon dioxide emissions. High temperature electrolysis may generate hydrogen and oxygen more efficiently than conventional electrolysis because energy losses resulting from the conversion of heat to electricity and electricity to heat are avoided by directly utilizing the heat produced from the nuclear reactions without producing electricity. Oxygen stream 672 mixes with mixed oxidizing fluid 676 and/or is mixed with oxidizing fluid 678. A portion or all of hydrogen stream 674 may be recycled to electrolysis unit 670 and used as an energy source. A portion or all of hydrogen stream 674 may be used for other purposes such as, but not limited to, a fuel for burners and/or a hydrogen source for in situ or ex situ hydrogenation of hydrocarbons.

[1236] Exhaust gas 680 from burners used to heat treatment area 666 may be directed to exhaust treatment unit 682. Exhaust gas 680 may include, but is not limited to, carbon dioxide and/or SO_x. In exhaust separation unit 682, carbon dioxide stream 684 is separated from SO_x stream 686. Separated carbon dioxide stream 684 may be mixed with diluent fluid 688, may be used as

a carrier fluid for oxidizing fluid 678, may be used as a drive fluid for producing hydrocarbons, and/or may be sequestered. SO_x stream 686 may be treated using known SO_x treatment methods (for example, sent to a Claus plant). Formation fluid 212' produced from heat treatment area 666 may be mixed with formation fluid 212 from other treatment areas and/or formation fluid 212' may enter separation unit 214. Separation unit 214 may separate the formation fluid into in situ heat treatment process liquid stream 216, in situ heat treatment process gas 218, and aqueous stream 220. Gas separation unit 222 may remove one or more components from in situ heat treatment process gas 218 to produce fuel 690 and one or more other streams 692. Fuel 690 may include, but is not limited to, hydrogen, sulfur compounds, hydrocarbons having a carbon number of at most 5, carbon oxides, nitrogen compounds, or mixtures thereof. In some embodiments, gas separation unit 222 uses chemical and/or physical treatment systems to remove or reduce the amount of carbon dioxide in fuel 690. Fuel 690 may enter fuel conduit 520 that provides fuel to oxidizers of oxidizer assemblies that heat treatment area 666.

[1237] In some embodiments, electrolysis unit 670 is powered by nuclear energy. Nuclear energy may be provided by a number of different types of available nuclear reactors and nuclear reactors currently under development (for example, generation IV reactors). In some embodiments, nuclear reactors may include a self-regulating nuclear reactor. Self-regulating nuclear reactors may include a fissile metal hydride which functions as both fuel for the nuclear reaction as well as a moderator for the nuclear reaction. The nuclear reaction may be moderated by the temperature driven mobility of the hydrogen isotope contained in the hydride. Self-regulating nuclear reactors may produce thermal power on the order of tens of megawatts per unit. Self-regulating nuclear reactors may operate at a maximum fuel temperature ranging from about 400 °C to about 900 °C, from about 450 °C to about 800 °C, and from about 500 °C to about 600 °C. Self-regulating nuclear reactors have several advantages including, but not limited to, a compact/modular design, ease of transport, and a simple cost effective design.

[1238] In some embodiments, nuclear reactors may include one or more very high temperature reactors (VHTRs). VHTRs may use helium as a coolant to drive a gas turbine for treating hydrocarbon fluids in situ, powering electrolysis unit 670 and/or for other purposes. VHTRs may produce heat for electrolysis units up to about 950 °C or more. In some embodiments, nuclear reactors may include a sodium-cooled fast reactor (SFR). SFRs may be designed on a smaller scale (for example, 50MWe), and therefore are more cost effective to manufacture on site for treating hydrocarbon fluids in situ, powering electrolysis units and/or for other purposes. SFRs may be of a modular design and potentially portable. SFRs may produce heat for electrolysis units ranging from about 500 °C to about 600 °C, from about 525 °C to about 575 °C, or from 540 °C to about 560 °C.

[1239] In some embodiments, pebble bed reactors may be employed to provide heat for electrolysis. Pebble bed reactors may produce up to about 165 MWe. Pebble bed reactors may produce heat for electrolysis units ranging from about 500 °C to about 1100 °C, from about 800 °C to about 1000 °C, or from about 900 °C to about 950 °C. In some embodiments, nuclear reactors may include supercritical-water-cooled reactors (SCWRs) based at least in part on previous light water reactors (LWR) and supercritical fossil-fired boilers. In some embodiments, SCWRs may be employed to provide heat for electrolysis. SCWRs may produce heat for electrolysis units ranging from about 400 °C to about 650 °C, from about 450 °C to about 550 °C, or from about 500 °C to about 550 °C.

[1240] In some embodiments, nuclear reactors may include lead-cooled fast reactors (LFRs). In some embodiments, LFRs may be employed to provide heat for electrolysis. LFRs may be manufactured in a range of sizes, from modular systems to several hundred megawatt or more sized systems. LFRs may produce heat for electrolysis units ranging from about 400 °C to about 900 °C, from about 500 °C to about 850 °C, or from about 550 °C to about 800 °C.

[1241] In some embodiments, nuclear reactors may include molten salt reactors (MSRs). In some embodiments, MSRs may be employed to provide heat for electrolysis. MSRs may include fissile, fertile, and fission isotopes dissolved in a molten fluoride salt with a boiling point of about 1,400 °C which function as both the reactor fuel and the coolant. MSRs may produce heat for electrolysis units ranging from about 400 °C to about 900 °C, from about 500 °C to about 850 °C, or from about 600 °C to about 800 °C.

[1242] In some embodiments, pulverized coal is the fuel used to heat the subsurface formation. The pulverized coal may be carried into the wellbores with a non-oxidizing fluid (for example, carbon dioxide and/or nitrogen). An oxidant may be mixed with the pulverized coal at several locations in the wellbore. The oxidant may be air, oxygen enriched air and/or other types of oxidizing fluids. Igniters located at or near the mixing locations initiate oxidation of the coal and oxidant. The igniters may be catalytic igniters, glow plugs, spark plugs, and/or electrical heaters (for example, an insulated conductor temperature limited heater with heating sections located at mixing locations of pulverized coal and oxidant) that are able to initiate oxidation of the oxidant with the pulverized coal.

[1243] The particles of the pulverized coal may be small enough to pass through flow orifices and achieve rapid combustion in the oxidant. The pulverized coal may have a particle size distribution from about 1 micron to about 300 microns, from about 5 microns to about 150 microns, or from about 10 microns to about 100 microns. Other pulverized coal particle size distributions may also be used. At 600 °C, the time to burn the volatiles in pulverized coal with a particle size distribution from about 10 microns to about 100 microns may be about one second.

[1244] In certain embodiments, a heater is located in a u-shaped wellbore or an L-shaped wellbore. The heater may include a heating section that is moved during treatment of the formation. Moving the heating section during treatment of the formation allows the heating section to be used over a wide area of the formation. Using the movable heating section may allow the heating section (and/or heater) to be significantly shorter in length than the length of the wellbore. The shorter heating section may reduce equipment costs and/or operating costs of the heater as compared to a longer heating section (for example, a heating section that has a length nearly as long as the length of the wellbore).

[1245] FIG. 156 depicts an embodiment of heater 412 with heating section 694 located in a u-shaped wellbore. Heater 412 is located in opening 386. In certain embodiments, opening 386 is a u-shaped opening with a substantially horizontal or inclined section in hydrocarbon layer 388 below overburden 400. Heater 412 may be a u-shaped heater with ends that extend out of both legs of the wellbore. In certain embodiments, heater 412 is an electrical resistance heater (a heater that provides heat by electrical resistance heating when energized with electrical current). In some embodiments, heater 412 is an oxidation heater (for example, a heater that oxidizes (combusts) fluids to produce heat). In certain embodiments, heater 412 is a circulating fluid heater such as a molten salt circulating heater.

[1246] In certain embodiments, heater 412 includes heating section 694. Heating section 694 may be the portion of heater 412 that provides heat to hydrocarbon layer 388. In certain embodiments, heating section 694 is the portion of heater 412 that has a higher electrical resistance than the rest of the heater such that the heating section is the only portion of the heater that provides substantial heat output to hydrocarbon layer 388. In some embodiments, heating section 694 is the portion of the heater that includes a downhole oxidizer (for example, downhole burner) or a plurality of downhole oxidizers. Other portions of heater 412 may be non-heating portions of the heater (for example, lead-in or lead-out sections of the heater) or portions of the heater that provide negligible heat output.

[1247] In certain embodiments, heater 412 is similar in length to the horizontal portion of opening 386 and heating section 694 is the portion of heater 412 shown in FIG. 156. Thus, heating section 694 is short in length compared to the horizontal portion of opening 386. In some embodiments, heating section 694 extends along the entire horizontal portion of heater 412 (or nearly the entire horizontal portion of the heater) and the heater is short in length compared to the horizontal portion of opening 386 such that the heating section is shorter in length than the horizontal portion of the opening.

[1248] In some embodiments, heating section 694 is at most ½ the length of the horizontal portion of opening 386, at most ¼ the length of the horizontal portion of opening 386, or at most

1/5 the length of the horizontal portion of opening 386. For example, the horizontal portion of opening 386 in hydrocarbon layer 388 may be between about 1500 m and about 3000 m in length and heating section 694 may be between about 300 m and about 500 m in length.

[1249] Having shorter heating section 694 allows heat to be provided to a small portion of hydrocarbon layer 388. The portion of hydrocarbon layer 388 heated by heating section 694 may be first volume 696. First volume 696 may be created around heater 412 proximate heating section 694.

[1250] In certain embodiments, heater 412 and heating section 694 are moved to provide heat to another portion of the formation. FIG. 157 depicts heater 412 with heating section 694 moved to heat second volume 698. In some embodiments, heating section 694 is moved by pulling heater 412 from one end of opening 386 (for example, pulling the heater from the left end of the opening, as shown in FIG. 157). In certain embodiments, heater 412 and heating section 694 are moved further to provide heat to third volume 700, as shown in FIG. 158.

[1251] In certain embodiments, first volume 696, second volume 698, and third volume 700 are heated sequentially from the first volume to the third volume. In some embodiments, portions of the volumes may overlap depending on the moving rate (movement speed) of heater 412 and heating section 694. In certain embodiments, heater 412 and heating section 694 are moved at a controlled rate. For example, heater 412 and heating section 694 may be moved after treating first volume 696 for a selected period of time or after a selected temperature is reached in the first volume.

[1252] Moving heater 412 and heating section 694 at the controlled rate may provide controlled heating in hydrocarbon layer 388. In some embodiments, the moving rate is controlled to control the amount of mobilization in hydrocarbon layer 388, first volume 696, second volume 698, and/or third volume 700. In some embodiments, the moving rate is controlled to control the amount of pyrolyzation in hydrocarbon layer 388, first volume 696, second volume 698, and/or third volume 700. The movement rate when mobilizing may be faster than the moving rate when pyrolyzing as more heat needs to be provided in a selected volume of the formation to result in pyrolyzation of hydrocarbons in the selected volume. In general, the moving rate of heater 412 and heating section 694 is controlled to achieve desired heating results for treatment of hydrocarbon layer 388. The moving rate may be determined, for example, by assessing treatment of hydrocarbon layer 388 using simulations and/or other calculations.

[1253] In certain embodiments, heater 412 is a u-shaped heater that is moved (for example, pulled) through u-shaped opening 386, as shown in FIGS. 156-158. In some embodiments, heater 412 is an L-shaped or J-shaped heater that is moved through a u-shaped opening (for example, the heater may be shaped like the heater depicted in FIG. 158). The L-shaped or J-

shaped heater may be moved by either pulling or pushing the heater from either end of the u-shaped opening.

[1254] In some embodiments, heater 412 is an L-shaped or J-shaped heater that is moved through an L-shaped or J-shaped opening. FIGS. 159-161 depict movement of L-shaped or J-shaped heater 412 as the heater is moved through opening 386 to heat first volume 696, second volume 698, and third volume 700.

[1255] FIG. 162 depicts an embodiment with two heaters 412A, 412B located in u-shaped opening 386. Heaters 412A, 412B may have heating sections 694A, 694B, respectively. Heaters 412A, 412B and heating sections 694A, 694B may be moved (pulled) away from each other, as shown by the arrows in FIG. 162. Moving heating sections 694A, 694B in opposite directions may create heated volumes in hydrocarbon layer 388 on each side of the middle of opening 386. In some embodiments, the heated volumes created by heating section 694A may substantially mirror the heated volumes created by heating section 694B. Thus, mirrored heated volumes may be sequentially created going in opposite directions from the middle of opening 386 by moving heating sections 694A, 694B away from each other at a controlled rate.

[1256] In certain embodiments, movable heaters allow for closer spacing between heaters during early phases of in situ heat treatment without increasing the number of wellbores in the formation by overlapping heating sections during the early phases of treatment. FIG. 163 depicts a top view of treatment area 666 treated using non-overlapping heating sections 694A, 694B in heaters 412A, 412B. As shown in FIG. 163, heaters 412A, 412B are L-shaped or J-shaped heaters located substantially horizontal or at an incline in the formation. Heaters 412A, 412B extend from build sections 702A, 702B, respectively.

[1257] In an embodiment, heating sections 694A, 694B heat in two phases. The solid sections of heaters 412A, 412B, shown as heating sections 694A, 694B in FIG. 163, are the first phase of heating. The solid sections provide heat in the center portion of treatment area 666. Heating sections 694A, 694B in the first phase are located end-to-end (the ends of the heating sections abut but do not touch) and do not overlap, as shown in FIG. 163. The cross-hatched sections of heaters 412A, 412B are the second phase of heating. In the second phase of heating, heating sections 694A, 694B move into the cross-hatched sections of heaters 412A, 412B to heat the edge portions of treatment area 666. In the embodiment depicted in FIG. 163, 18 heaters 412A, 412B are used to heat treatment area 666.

[1258] FIG. 164 depicts a top view of treatment area 666 treated using overlapping heating sections 694A, 694B in the first phase of heating using heaters 412A, 412B. In the embodiment depicted in FIG. 164, heaters 412A, 412B heat treatment area 666 in two phases such as in the embodiment depicted in FIG. 163. In the first phase, however, heating sections 694A, 694B

overlap and are located adjacent to each other, as shown in FIG. 164. Thus, heating sections 694A, 694B (and heaters 412A, 412B) have closer spacing during the first phase in the embodiment depicted in FIG. 164 than the embodiment depicted in FIG. 163. For example, heating sections 694A, 694B shown in FIG. 164 have half the spacing of the heating sections shown in FIG. 163. In addition, heat provided by heating sections 694A during the first phase in the embodiment depicted in FIG. 164 overlaps with heat provided by heating sections 694B, which also increases the heat provided to the center portion of treatment area 666. The closer spacing may accelerate heating of the center portion of treatment area 666 without increasing the number of heaters 412A, 412B in the treatment area (there are still 18 heaters in the embodiment depicted in FIG. 164). In addition, heat provided by heating sections 694A during the first phase in the embodiment depicted in FIG. 164 overlaps with heat provided by heating sections 694B, which increases the heat provided to the center portion of treatment area 666. During the second phase of heating, heating sections 694A, 694B (the cross-hatched sections) in the embodiment depicted in FIG. 164 may have similar spacing as the second phase heating sections in the embodiment depicted in FIG. 163.

[1259] As shown in the embodiment depicted in FIG. 164, build section 702B may be moved closer to build section 702A in order to achieve the closer heater spacing in the first phase of heating. Thus, the volume of treatment area 666 heated during the two phases of heating may be smaller than the volume heated in the embodiment depicted in FIG. 163. In certain embodiments, additional heaters may be placed in remaining volume 704 of treatment area 666. These additional heaters may heat remaining volume 704 such that a similar volume of treatment area 666 is heated in the embodiment depicted in FIG. 164 as the volume heated in the embodiment depicted in FIG. 163. The additional heaters used to heat remaining volume 704, depicted in FIG. 164, may be placed in the formation at later times during treatment of the formation. The additional heaters may have a discounted cost compared to heaters formed in the formation at earlier times.

[1260] In some embodiments, fast fluidized transport line systems may be used for subsurface heating. Fast fluidized transport line systems may have significantly higher overall energy efficiency as compared to using electrical heating. The systems may have high heat transfer efficiency. Low value fuel (for example, bitumen or pulverized coal) may be used as the heat source. Solid transport line circulation is commercially proven technology having relatively reliable operation.

[1261] Fast fluidized transport systems may include one or more combustion units, wellbores, a treatment area, and piping to transport fluidized material from the combustion units through the wellbores to heat the treatment area. In some embodiments, one or more of combustion units

used to heat the formation are furnaces, nuclear reactors, or other high temperature heat sources. Such combustion units heat fluidized material that passes through the combustion units. Each combustion unit may provide hot fluidized material to a large number of u-shaped wellbores. For example, one combustion unit may supply hot fluidized material to 20 or more u-shaped wellbores. In some embodiments, the u-shaped wellbores are formed so that the surface footprint has long rows of inlet and exit legs of u-shaped wellbores. The exit legs and inlet legs of these u-shaped wellbores are located in adjacent rows. Additional fluidized transport systems would be located on the same row to supply all of the u-shaped wellbores on the row. Also, additional fluidized transport systems would be positioned on adjacent rows to supply inlet legs and outlet legs of the adjacent rows.

[1262] Fluidized material may include coal particles (for example, pulverized coal), other hydrocarbon or carbon containing material (for example, bitumen and coke), and heat carrier particles. The heat carrier particles may include, but are not limited to, sand, silica, ceramic particles, waste fluidized catalytic cracking catalyst, other particles used for heat transfer, or mixtures thereof. In some embodiments, the particle range distribution of the fluidized material may span from between about 5 and 200 microns.

[1263] A portion of the hydrocarbon content in fluidized material may combust and/or pyrolyze in the combustion units. Fluidized material may still have a significant carbon (coke) and/or hydrocarbon content after passing through the combustion unit. The oxidant may react with the carbon and/or hydrocarbons in the fluidized material in the u-shaped conduits. The combustion of hydrocarbons and carbon in the fluidized material may maintain a high temperature of the fluidized material and/or generate heat that transfers to the formation.

[1264] Gas lifting may facilitate transport of the fluidized material in the u-shaped conduits. Multiple valves in the outlet legs may allow entry of lift gas into the outlet legs to transport the fluidized material to the treatment area. In some embodiments, the lift gas is air. Other gases may be used as the lift gas.

[1265] In some in situ heat treatment process embodiments, a circulation system is used to heat the formation. Using the circulation system for in situ heat treatment of a hydrocarbon containing formation may reduce energy costs for treating the formation, reduce emissions from the treatment process, and/or facilitate heating system installation. In certain embodiments, the circulation system is a closed loop circulation system. FIG. 165 depicts a schematic representation of a system for heating a formation using a circulation system. The system may be used to heat hydrocarbons that are relatively deep in the ground and that are in formations that are relatively large in extent. In some embodiments, the hydrocarbons may be 100 m, 200 m, 300 m or more below the surface. The circulation system may also be used to heat hydrocarbons

that are shallower in the ground. The hydrocarbons may be in formations that extend lengthwise up to 1000 m, 3000 m, 5000 m, or more. The heaters of the circulation system may be positioned relative to adjacent heaters such that superposition of heat between heaters of the circulation system allows the temperature of the formation to be raised at least above the boiling point of aqueous formation fluid in the formation.

[1266] In some embodiments, heaters 412 are formed in the formation by drilling a first wellbore and then drilling a second wellbore that connects with the first wellbore. Piping may be positioned in the u-shaped wellbore to form u-shaped heater 412. Heaters 412 are connected to heat transfer fluid circulation system 706 by piping. In some embodiments, the heaters are positioned in triangular patterns. In some embodiments, other regular or irregular patterns are used. Production wells and/or injection wells may also be located in the formation. The production wells and/or the injection wells may have long, substantially horizontal sections similar to the heating portions of heaters 412, or the production wells and/or injection wells may be otherwise oriented (for example, the wells may be vertically oriented wells, or wells that include one or more slanted portions).

[1267] As depicted in FIG. 165, heat transfer fluid circulation system 706 may include heat supply 708, first heat exchanger 710, second heat exchanger 712, and fluid movers 714. Heat supply 708 heats the heat transfer fluid to a high temperature. Heat supply 708 may be a furnace, solar collector, chemical reactor, nuclear reactor, fuel cell, and/or other high temperature source able to supply heat to the heat transfer fluid. If the heat transfer fluid is a gas, fluid movers 714 may be compressors. If the heat transfer fluid is a liquid, fluid movers 714 may be pumps.

[1268] After exiting formation 492, the heat transfer fluid passes through first heat exchanger 710 and second heat exchanger 712 to fluid movers 714. First heat exchanger 710 transfers heat between heat transfer fluid exiting formation 492 and heat transfer fluid exiting fluid movers 714 to raise the temperature of the heat transfer fluid that enters heat supply 708 and reduce the temperature of the fluid exiting formation 492. Second heat exchanger 712 further reduces the temperature of the heat transfer fluid. In some embodiments, second heat exchanger 712 includes or is a storage tank for the heat transfer fluid.

[1269] Heat transfer fluid passes from second heat exchanger 712 to fluid movers 714. Fluid movers 714 may be located before heat supply 708 so that the fluid movers do not have to operate at a high temperature.

[1270] In an embodiment, the heat transfer fluid is carbon dioxide. Heat supply 708 is a furnace that heats the heat transfer fluid to a temperature in a range from about 700 °C to about 920 °C, from about 770 °C to about 870 °C, or from about 800 °C to about 850 °C. In an embodiment, heat supply 708 heats the heat transfer fluid to a temperature of about 820 °C. The heat transfer

fluid flows from heat supply 708 to heaters 412. Heat transfers from heaters 412 to formation 492 adjacent to the heaters. The temperature of the heat transfer fluid exiting formation 492 may be in a range from about 350 °C to about 580 °C, from about 400 °C to about 530 °C, or from about 450 °C to about 500 °C. In an embodiment, the temperature of the heat transfer fluid exiting formation 492 is about 480 °C. The metallurgy of the piping used to form heat transfer fluid circulation system 706 may be varied to significantly reduce costs of the piping. High temperature steel may be used from heat supply 708 to a point where the temperature is sufficiently low so that less expensive steel can be used from that point to first heat exchanger 710. Several different steel grades may be used to form the piping of heat transfer fluid circulation system 706.

[1271] In some embodiments, solar salt (for example, a salt containing 60 wt% $NaNO_3$ and 40 wt% KNO_3) is used as the heat transfer fluid in the circulated fluid system. Solar salt may have a melting point of about 230 °C and an upper working temperature limit of about 565 °C. In some embodiments, $LiNO_3$ (for example, between about 10% by weight and about 30% by weight $LiNO_3$) may be added to the solar salt to produce tertiary salt mixtures with wider operating temperature ranges and lower melting temperatures with only a slight decrease in the maximum working temperature as compared to solar salt. The lower melting temperature of the tertiary salt mixtures may decrease the preheating requirements and allow the use of pressurized water and/or pressurized brine as a heat transfer fluid for preheating the piping of the circulation system. The corrosion rates of the metal of the heaters due to the tertiary salt compositions at 550 °C is comparable to the corrosion rate of the metal of the heaters due to solar salt at 565 °C. TABLE 5 shows melting points and upper limits for solar salt and tertiary salt mixtures. Aqueous solutions of tertiary salt mixtures may transition into a molten salt upon removal of water without solidification, thus allowing the molten salt to be provided and/or stored as aqueous solutions.

TABLE 5

NO_3 Salt	Composition of NO_3 Salt (weight %)	Melting Point (°C) of NO_3 salt	Upper working temperature limit (°C) of NO_3 salt
Na:K	60:40	230	600
Li:Na:K	12:18:70	200	550
Li:Na:K	20:28:52	150	550
Li:Na:K	27:33:40	160	550
Li:Na:K	30:18:52	120	550

[1272] In certain embodiments, heat supply 708 is a furnace that heats the heat transfer fluid to a temperature of about 560 °C. The return temperature of the heat transfer fluid may be from about 350 °C to about 450 °C. Piping from heat transfer fluid circulation system 706 may be insulated and/or heat traced to facilitate startup and to ensure fluid flow.

[1273] In some embodiments, vertical, slanted, or L-shaped wellbores are used instead of u-shaped wellbores (for example, wellbores that have an entrance at a first location and an exit at another location). FIG. 166A depicts L-shaped heater 412. Heater 412 may be coupled to heat transfer fluid circulation system 706 and may include inlet conduit 716, and outlet conduit 718. Heat transfer fluid circulation system 706 may supply heat transfer fluid to multiple heaters. Heat transfer fluid from heat transfer fluid circulation system 706 may flow down inlet conduit 716 and back up outlet conduit 718. Inlet conduit 716 and outlet conduit 718 may be insulated through overburden 400. In some embodiments, inlet conduit 716 is insulated through overburden 400 and hydrocarbon containing layer 388 to inhibit undesired heat transfer between ingoing and outgoing heat transfer fluid.

[1274] In some embodiments, portions of wellbore 490 adjacent to overburden 400 are larger than portions of the wellbore adjacent to hydrocarbon containing layer 388. Having a larger opening adjacent to the overburden may allow for accommodation of insulation used to insulate inlet conduit 716 and/or outlet conduit 718. Some heat loss to the overburden from the return flow may not affect the efficiency significantly, especially when the heat transfer fluid is molten salt or another fluid that needs to be heated to remain a liquid. The heated overburden adjacent to heater 412 may maintain the heat transfer fluid as a liquid for a significant time should circulation of heat transfer fluid stop. Having some allowance for heat transfer to overburden 400 may eliminate the need for expensive insulation systems between outlet conduit 718 and the overburden. In some embodiments, insulative cement is used between overburden 400 and outlet conduit 718.

[1275] For vertical, slanted, or L-shaped heaters, the wellbores may be drilled longer than needed to accommodate non-energized heaters (for example, installed but inactive heaters). Thermal expansion of the heaters after energization may cause portions of the heaters to move into the extra length of the wellbores designed to accommodate the thermal expansion of the heaters. For L-shaped heaters, remaining drilling fluid and/or formation fluid in the wellbore may facilitate movement of the heater deeper into the wellbore as the heater expands during preheating and/or heating with heat transfer fluid.

[1276] For vertical or slanted wellbores, the wellbores may be drilled deeper than needed to accommodate the non-energized heaters. When the heater is preheated and/or heated with the heat transfer fluid, the heater may expand into the extra depth of the wellbore. In some

embodiments, an expansion sleeve may be attached at the end of the heater to ensure available space for thermal expansion in case of unstable boreholes.

[1277] In some embodiments, a liner may be used in a wellbore and/or be coupled to a heater to inhibit fluids from mixing with circulating molten salts. In some embodiments, the liner may inhibit hydrocarbons from mixing with a heat transfer fluid (for example, one or more molten salts). FIG. 166B, depicts heater 412 with liner 1428. Liner 1428 may include one or more materials that are chemically resistant to corrosive materials (for example, metal or ceramic based materials).

[1278] As shown in FIG. 166B, liner 1428 is positioned in a wellbore. In some embodiments, liner 1428 may be placed in the wellbore or the wellbore may be coated with chemically resistant material prior to positioning heater 412. In some embodiments, the liner may be coupled to the circulating molten salt heater. In some embodiments, the liner may include a coating on either the inner and/or outer surface of one or more of the conduits forming a circulating molten salt heater. In some embodiments, the liner may include a conduit substantially surrounding at least a portion of the conduit. In some embodiments, piping includes a liner that is resistant to corrosion by the fluid.

[1279] FIG. 167 depicts a schematic representation of an embodiment of a portion of vertical heater 412. Heat transfer fluid circulation system 706 may provide heat transfer fluid to inlet conduit 716 of heater 412. Heat transfer fluid circulation system 706 may receive heat transfer fluid from outlet conduit heat 718. Inlet conduit 716 may be secured to outlet conduit 718 by welds 720. Inlet conduit 716 may include insulating sleeve 722. Insulating sleeve 722 may be formed of a number of sections. Each section of insulating sleeve 722 for inlet conduit 716 is able to accommodate the thermal expansion caused by the temperature difference between the temperature of the inlet conduit and the temperature outside the insulating sleeve. Change in length of inlet conduit 716 and insulation sleeve 722 due to thermal expansion is accommodated in outlet conduit 718.

[1280] Outlet conduit 718 may include insulating sleeve 722'. Insulating sleeve 722' may end near the boundary between overburden 400 and hydrocarbon layer 388. In some embodiments, insulating sleeve 722' is installed using a coiled tubing rig. An upper first portion of insulating sleeve 722' may be secured to outlet conduit 718 above or near wellhead 392 by weld 720. Heater 412 may be supported in wellhead 392 by a coupling between the outer support member of insulating sleeve 722' and the wellhead. The outer support member of insulating sleeve 722' may have sufficient strength to support heater 412.

[1281] In some embodiments, insulating sleeve 722' includes a second portion (insulating sleeve portion 722'') that is separate and lower than the first portion of insulating sleeve 722'.

Insulating sleeve portion 722'' may be secured to outlet conduit 718 by welds 720 or other types of seals that can withstand high temperatures below packer 724. Welds 720 between insulating sleeve portion 722'' and outlet conduit 718 may inhibit formation fluid from passing between the insulating sleeve and the outlet conduit. During heating, differential thermal expansion between the cooler outer surface and the hotter inner surface of insulating sleeve 722' may cause separation between the first portion of the insulating sleeve and the second portion of the insulating sleeve (insulating sleeve portion 722''). This separation may occur adjacent to the overburden portion of heater 412 above packer 724. Insulating cement between casing 398 and the formation may further inhibit heat loss to the formation and improve the overall energy efficiency of the system.

[1282] Packer 724 may be a polished bore receptacle. Packer 724 may be fixed to casing 398 of wellbore 490. In some embodiments, packer 724 is 1000 m or more below the surface. Packer 724 may be located at a depth above 1000 m, if desired. Packer 724 may inhibit formation fluid from flowing from the heated portion of the formation up the wellbore to wellhead 392. Packer 724 may allow movement of insulating sleeve portion 722'' downwards to accommodate thermal expansion of heater 412.

[1283] In some embodiments, wellhead 392 includes fixed seal 726. Fixed seal 726 may be a second seal that inhibits formation fluid from reaching the surface through wellbore 490 of heater 412.

[1284] FIG. 168 depicts a schematic representation of another embodiment of a portion of vertical heater 412 in wellbore 490. The embodiment depicted in FIG. 168 is similar to the embodiment depicted in FIG. 167, but fixed seal 726 is located adjacent to overburden 400, and sliding seal 728 is located in wellhead 392. The portion of insulating sleeve 722' from fixed seal 726 to wellhead 392 is able to expand upward out of the wellhead to accommodate thermal expansion. The portion of heater located below fixed seal 726 is able to expand into the excess length of wellbore 490 to accommodate thermal expansion.

[1285] In some embodiments, the heater includes a flow switcher. The flow switcher may allow the heat transfer fluid from the circulation system to flow down through the overburden in the inlet conduit of the heater. The return flow from the heater may flow upwards through the annular region between the inlet conduit and the outlet conduit. The flow switcher may change the downward flow from the inlet conduit to the annular region between the outlet conduit and the inlet conduit. The flow switcher may also change the upward flow from the inlet conduit to the annular region. The use of the flow switcher may allow the heater to operate at a higher temperature adjacent to the treatment area without increasing the initial temperature of the heat transfer fluid provided to the heaters.

[1286] For vertical, slanted, or L-shaped heaters where the flow of heat transfer fluid is directed down the inlet conduit and returns through the annular region between the inlet conduit and the outlet conduit, a temperature gradient may form in the heater with the hottest portion being located at a distal end of the heater. For L-shaped heaters, horizontal portions of a set of first heaters may be alternated with the horizontal portions of a second set of heaters. The hottest portions used to heat the formation of the first set of heaters may be adjacent to the coldest portions used to heat the formation of the second set of heaters, while the hottest portions used to heat the formation of the second set of heaters are adjacent to the coldest portions used to heat the formation of the first set of heaters. For vertical or slanted heaters, flow switchers in selected heaters may allow the heaters to be arranged with the hottest portions used to heat the formation of first heaters adjacent to coldest portions used to heat the formation of second heaters. Having hottest portions used to heat the formation of the first set of heaters adjacent to coldest portions used to heat the formation of the second set of heaters may allow for more uniform heating of the formation.

[1287] In certain embodiments, treatment areas in a formation are treated in patterns (for example, regular or irregular patterns). FIG. 169 depicts a schematic representation of a corridor pattern system used to treat treatment area 730. Heat transfer circulation systems 706, 706' may be positioned on each side of treatment area 730. Inlet wellheads 732 and outlet wellheads 734 of subsurface heaters 412 may be positioned in rows along each side of the treatment area. Although one row of wellheads is depicted on each side of treatment area 730, sufficient wells may be formed in the formation such that heaters 412 in the formation form a three dimensional pattern in the treatment area with well spacings that allow for superposition of heat from adjacent heaters. Hot heat transfer fluid from circulation system 706 flows through manifolds to inlet wellheads 732 on the first side of treatment area 730. The heat transfer fluid passes through heaters 412 to outlet wellbores 734 on the second side of treatment area 730. Heat is transferred from the heat transfer fluid to treatment area 730 as the heat transfer fluid travels from inlet wellheads 732 to outlet wellheads 734. The heat transfer fluid passes from outlet wellheads 734 through manifolds to heat transfer fluid circulation system 706' on the second side of treatment area 730. Additional corridor patterns above, below, and/or to the sides of treatment area 730 may be processed during or after in heat situ treatment of treatment area 730.

[1288] FIG. 170 depicts a schematic representation of a radial pattern system used to treat treatment area 730. Treatment area 730 may be an annular region located between inlet wellheads 732 and outlet wellheads 734. Central heat transfer fluid circulation system 706 may be positioned near to or on a first side (for example, at or near the center or on the inside) of treatment area 730. Outer heat transfer fluid circulation systems 706' may be positioned near to

or on a second side (for example, on the perimeter) of treatment area 730. Inlet wellheads 732 and outlet wellheads 734 of subsurface heaters 412 may be positioned in rings along each side of the treatment area. Although one ring of inlet wellheads 732 and one ring of outlet wellheads 734 is depicted on each side of treatment area 730, sufficient wells may be formed in the formation such that heaters 412 in the formation form a three-dimensional pattern in the treatment area with well spacings that allow for superposition of heat between adjacent heaters. Hot heat transfer fluid from central heat transfer fluid circulation system 706 flows through manifolds to inlet wellheads on the first side of treatment area 730. The heat transfer fluid passes through heaters 412 to outlet wellbores 734 on the second side of treatment area 730. Heat is transferred from the heat transfer fluid to the treatment area as the heat transfer fluid travels from inlet wellheads 732 to outlet wellheads 734. The heat transfer fluid passes from outlet wellheads 734 on the second side of treatment area 730 through manifolds to outer heat transfer fluid circulation systems 706' on the second side of the treatment area. Heat transfer fluid heated by outer heat transfer fluid circulation systems 706' passes through manifolds to inlet wellheads 732 on the second side of the treatment area. The heat transfer fluid passes through heaters 412 to outlet wellheads 734 on the first side of treatment area 730. The heat transfer fluid flows through manifolds to central heat transfer fluid circulation system 706. In certain embodiments, additional radial patterns are formed at other locations in the formation.

[1289] In some embodiments, only a portion of the ring of treatment area 730 is treated. In some embodiments, the entire ring of the treatment area, or a portion of the treatment area is treated in sections. For example, one or more central circulation systems 706 may supply heat transfer fluid to a first set of heaters. The first set of heaters, along with a second set of return heaters may treat a first section of about one eighth (or 45° arc) of the treatment area. Other section sizes may also be chosen. The heat transfer fluid from central circulation systems 706 may be received by one or more outer circulation systems 706'. Outer circulation systems 706' may return heat transfer fluid to central circulation systems 706. After completion of heating of the first section of treatment area 730, an adjacent section to the first section or another section of the treatment area not adjacent to the first section may be treated. Outer circulation systems 706' may be mobile such that the outer circulation systems can be used to treat different sections of the treatment area. In some embodiments, one or more production wells for a particular section may be used to produce formation fluid during the treatment of another section.

[1290] Due to the radial layout of heaters 412, the heater density and/or heat input per volume of formation increases from the second side of treatment area 730 towards the first side of the treatment area. The heater density and/or heat input per volume change may establish a temperature gradient through treatment area 730 with the average temperature of the treatment

area increasing from the second side of the treatment area towards the first side of the treatment area (for example, from the perimeter of the treatment area towards the center of the treatment area). For example, the average temperature near the first side of treatment area 730 may be about 300°C to about 350 °C while the average temperature near the second side may be about 180°C to about 220 °C. The higher temperature near the first side of treatment area 730 may result in the mobilization of hydrocarbons towards the second side of the treatment area.

[1291] FIG. 171 depicts a plan view of an embodiment of wellbore openings on a first side of treatment area 730. Heat transfer fluid entries 736 into the formation alternate with heat transfer fluid exits 738. Alternating heat transfer fluid entries 736 and heat transfer fluid exits 738 may allow for more uniform heating of the hydrocarbons in treatment area 730.

[1292] In some embodiments, piping and surface facilities for the circulation system may allow the direction of heat transfer fluid flow through the formation to be changed. Changing the direction of heat transfer fluid flow through the formation allows each end of a u-shaped wellbore to alternately receive the heat transfer fluid at the hottest temperature of the heat transfer fluid for a period of time, which may result in more uniform heating of the formation. The direction of heat transfer fluid may be changed at desired time intervals. The desired time interval may be, for example, about a year, about six months, about three months, about two months, or any other desired time interval.

[1293] In some embodiments, a liquid heat transfer fluid is used as the heat transfer fluid. The liquid heat transfer fluid may be natural or synthetic oil, molten metal, molten salt, or another type of high temperature heat transfer fluid. A liquid heat transfer fluid may allow for smaller diameter piping and reduced pumping and/or compression costs. In some embodiments, the piping is made of a material resistant to corrosion by the liquid heat transfer fluid. In some embodiments, the piping is lined with a material that is resistant to corrosion by the liquid heat transfer fluid. For example, if the heat transfer fluid is a molten fluoride salt, the piping may include nickel liner (for example, a 10 mil thick nickel liner). Such piping may be formed by roll bonding a nickel strip onto a strip of the piping material (for example, stainless steel), rolling the composite strip, and longitudinally welding the composite strip to form the piping. Other techniques known in the art may also be used. Nickel corrosion by the molten fluoride salt may be at most 1 mil per year at a temperature of about 840 °C.

[1294] In some embodiments, two or more heat transfer fluids (for example, air, superheated steam, synthetic heat transfer oils, and/or molten salts) are employed to transfer thermal energy to and/or from a hydrocarbon containing formation. In some embodiments, a first heat transfer fluid is a synthetic heat transfer oil (for example, DowTherm®A manufactured by Dow Chemical Company, U.S.A). A first heat transfer fluid may be heated, for example, with a nuclear reactor

or a furnace. The first heat transfer fluid may be circulated through a plurality of wellbores in at least a portion of the formation in order to heat the portion of the formation. The first heat transfer fluid may have a first temperature range in which the first heat transfer fluid is in a liquid form and stable. Temperature of the first heat transfer fluid may be in a range from about 150 °C to about 400 °C. An inlet of the piping may be heated to a predetermined temperature (for example, heated to a temperature in a range from about 400 °C to about 600 °C). The first heat transfer fluid may be circulated through the portion of the formation until the portion reaches a temperature in a desired temperature range (for example, about 230 °C or a temperature towards the upper end of the first heat transfer fluid temperature range). The first heat transfer fluid may be circulated through the piping in the formation at, for example, a rate of 3 kg/sec to 15 kg/sec, a rate of 4 kg /sec to 12 kg /sec, or a rate of 5 kg/sec to 10 kg/sec. A flow rate of the first heat transfer fluid may be selected based on, for example, the number of days desired for preheating (for example, 10 days, 50 days, or 120 days) and the inlet temperature of the piping. For example, air may be circulated at 6.2 kg/sec through a 5" diameter u-shaped heater having an inlet temperature of 600 °C to preheat a section of a formation to 230 °C in 10 days. Circulating synthetic heat transfer oil at a flow rate of 4.3 kg/sec may preheat the section in the same period of time. To preheat the section to 230 °C in 10 days using superheated steam as the heat transfer fluid, a flow rate of 3.2 kg/sec may be used.

[1295] A second heat transfer fluid may be heated (for example, with a nuclear reactor). The second heat transfer fluid may have a second temperature range in which the second heat transfer fluid is in a liquid form and stable. An upper end of the second temperature range may be hotter and above the first temperature range. A lower end of the second temperature range may overlap with the first temperatures range. The second heat transfer fluid may be circulated through the plurality of wellbores in the portion of the formation in order to heat the portion of the formation to a higher temperature than is possible with the first heat transfer fluid.

[1296] The advantages of using two or more different heat transfer fluids may include, for example, the ability to heat the portion of the formation to a much higher temperature than is normally possible while using other supplementary heating methods (for example, electric heaters) as little as possible to increase overall efficiency (for example, electric heaters). Using two or more different heat transfer fluids may be necessary if a heat transfer fluid with a large enough temperature range capable of heating the portion of the formation to the desired temperature is not available. Heating with two or more heat transfer fluids may deliver greater than 1000 W/ft of energy to the formation, thus allowing the formation to be preheated in a relatively short period of time (for example, less than 120 days).

[1297] In some embodiments, after the portion of the hydrocarbon containing formation has been heated to a desired temperature range, the first heat transfer fluid may be recirculated through the portion of the formation. The first heat transfer fluid may not be heated before recirculation through the formation (other than heating the heat transfer fluid to the melting point if necessary in the case of molten salts). The first heat transfer fluid may be heated using the thermal energy already stored in the portion of the formation from prior in situ heat treatment of the formation. The first heat transfer fluid may then be transferred out of the formation such that the thermal energy recovered by the first heat transfer fluid may be reused for some other process in the portion of the formation, in a second portion of the formation, and/or in an additional formation.

[1298] In some embodiments, the diameter of the conduit through which the heat transfer fluid flows in overburden 400 may be smaller than the diameter of the conduit through the treatment area. For example, the diameter of the pipe in the overburden may be about 3" (about 7.6 cm), and the diameter of the pipe adjacent to the treatment area may be about 5" (about 12.7 cm). The smaller diameter pipe through overburden 400 may reduce heat loss from the heat transfer fluid to the overburden. Reducing heat loss to overburden 400 reduces cooling of the heat transfer fluid supplied to the conduit adjacent to hydrocarbon layer 388. In certain embodiments, any increased heat loss in the smaller diameter pipe due to increased velocity of the heat transfer fluid through the smaller diameter pipe is offset by the smaller surface area of the smaller diameter pipe and the decrease in residence time of the heat transfer fluid in the smaller diameter pipe.

[1299] Heat transfer fluid from heat supply 708 of heat transfer fluid circulation system 706 passes through overburden 400 of formation 492 to hydrocarbon layer 388. In certain embodiments, portions of heaters 412 extending through overburden 400 are insulated. In some embodiments, the insulation or part of the insulation is a polyimide insulating material. In some embodiments, inlet portions of heaters 412 in hydrocarbon layer 388 have tapering insulation to reduce overheating of the hydrocarbon layer near the inlet of the heater into the hydrocarbon layer.

[1300] The overburden section of heaters 412 may be insulated to prevent or inhibit heat loss into non-hydrocarbon bearing zones of the formation. In some embodiments, thermal insulation is provided by a conduit-in-conduit design. The heat transfer fluid flows through the inner conduit. Insulation fills the space between the inner conduit and the outer conduit. An effective insulation may be a combination of metal foil to inhibit radiative heat loss and microporous silica powder to inhibit conductive heat loss. Reducing the pressure in the space between the inner conduit and the outer conduit by pulling a vacuum during assembly and/or with getters may further reduce heat losses when using the conduit-in-conduit design. To account for the differential thermal expansion of the inner conduit and the outer conduit, the inner conduit may

be pre-stressed or made of a material with low thermal expansion (for example, Invar alloys). The insulated conduit-in-conduit may be installed continuously in conjunction with coiled tubing installation. Insulated conduit-in-conduit systems may be available from Industrial Thermo Polymers Limited (Ontario, Canada) and Oil Tech Services, Inc. (Houston, Texas, U.S.A.). Other effective insulation materials include, but are not limited to, ceramic blankets, foam cements, cements with low thermal conductivity aggregates (such as vermiculite), Izoflex™ insulation, and aerogel/glass-fiber composites such as those provided by Aspen Aerogels, Inc. (Northborough, Massachusetts, U.S.A.).

[1301] FIG. 172 depicts a cross-sectional view of an embodiment of overburden insulation. Insulating cement 740 may be placed between casing 398 and formation 492. Insulating cement 740 may also be placed between heat transfer fluid conduit 742 and casing 398.

[1302] FIG. 173 depicts a cross-sectional view of an alternate embodiment of overburden insulation that includes insulating sleeve 722 around heat transfer fluid conduit 742. Insulating sleeve 722 may include, for example, an aerogel. Gap 744 may be located between insulating sleeve 722 and casing 398. The emissivities of insulating sleeve 722 and casing 398 may be low to inhibit radiative heat transfer in gap 744. A non-reactive gas may be placed in gap 744 between insulating sleeve 722 and casing 398. Gas in gap 744 may inhibit conductive heat transfer between insulating sleeve 722 and casing 398. In some embodiments, a vacuum may be drawn and maintained in gap 744. Insulating cement 740 may be placed between casing 398 and formation 492. In some embodiments, insulating sleeve 722 has a significantly smaller thermal conductivity value than the thermal conductivity value of insulating cement. In certain embodiments, the insulation provided by the insulation depicted in FIG. 173 may be better than the insulation provided by the insulation depicted in FIG. 172.

[1303] FIG. 174 depicts a cross-sectional view of an alternative embodiment of overburden insulation with insulating sleeve 722 around heat transfer fluid conduit 742, vacuum gap 746 between the insulating sleeve and conduit 748, and gap 744 between the conduit and casing 398. Insulating cement 740 may be placed between casing 398 and formation 492. A non-reactive gas may be placed in gap 744 between conduit 748 and casing 398. In some embodiments, a vacuum may be drawn and maintained in gap 744. A vacuum may be drawn and maintained in vacuum gap 746 between insulating sleeve 722 and conduit 748. Insulating sleeve 722 may include layers of insulating material separated by foil 750. The insulation material may be, for example, aerogel. The layers of insulating material separated by foil 750 may provide substantial insulation around heat transfer fluid conduit 742. Vacuum gap 746 may inhibit radiative, convective, and/or conductive heat transfer between insulating sleeve 722 and conduit 748. A non-reactive gas may be placed in gap 744. The emissivities of conduit 748 and casing 398 may

be low to inhibit radiative heat transfer between the conduit and the casing. In certain embodiments, the insulation provided by the insulation depicted in FIG. 174 may be better than the insulation provided by the insulation depicted in FIG. 173.

[1304] When heat transfer fluid is circulated through piping in the formation to heat the formation, the heat of the heat transfer fluid may cause changes in the piping. The heat in the piping may reduce the strength of the piping since Young's modulus and other strength characteristics vary with temperature. The high temperatures in the piping may raise creep concerns, may cause buckling conditions, and may move the piping from the elastic deformation region to the plastic deformation region.

[1305] Heating the piping may cause thermal expansion of the piping. For long heaters placed in the wellbore, the piping may expand 20 m or more. In some embodiments, the horizontal portion of the piping is cemented in the formation with thermally conductive cement. Care may need to be taken to ensure that there are no significant gaps in the cement to inhibit expansion of the piping into the gaps and possible failure. Thermal expansion of the piping may cause ripples in the pipe and/or an increase in the wall thickness of the pipe.

[1306] For long heaters with gradual bend radii (for example, about 10° of bend per 30 m), thermal expansion of the piping may be accommodated in the overburden or at the surface of the formation. After thermal expansion is completed, the position of the heaters relative to the wellheads may be secured. When heating is finished and the formation is cooled, the position of the heaters may be unsecured so that thermal contraction of the heaters does not destroy the heaters.

[1307] FIGS. 175-185 depict schematic representations of various methods for accommodating thermal expansion. In some embodiments, change in length of the heater due to thermal expansion may be accommodated above the wellhead. After substantial changes in the length of the heater due to thermal expansion cease, the heater position relative to the wellhead may be fixed. The heater position relative to the wellhead may remain fixed until the end of heating of the formation. After heating is ended, the position of the heater relative to the wellhead may be freed (unfixed) to accommodate thermal contraction of the heater as the heater cools.

[1308] FIG. 175 depicts a representation of bellows 752. Length *L* of bellows 752 may change to accommodate thermal expansion and/or contraction of piping 754. Bellows 752 may be located subsurface or above the surface. In some embodiments, bellows 752 includes a fluid that transfers heat out of the wellhead.

[1309] FIG. 176A depicts a representation of piping 754 with expansion loop 756 above wellhead 392 for accommodating thermal expansion. Sliding seals in wellhead 392, stuffing boxes, or other pressure control equipment of the wellhead allow piping 754 to move relative to

casing 398. Expansion of piping 754 is accommodated in expansion loop 756. In some embodiments, two or more expansion loops 756 are used to accommodate expansion of piping 754.

[1310] FIG. 176B depicts a representation of piping 754 with coiled or spooled piping 758 above wellhead 392 for accommodating thermal expansion. Sliding seals in wellhead 392, stuffing boxes, or other pressure control equipment of the wellhead allow piping 754 to move relative to casing 398. Expansion of piping 754 is accommodated in coiled piping 758. In some embodiments, expansion is accommodated by coiling the portion of the heater exiting the formation on a spool using a coiled tubing rig.

[1311] In some embodiments, coiled piping 758 may be enclosed in insulated volume 760, as shown in FIG. 176C. Enclosing coiled piping 758 in insulated volume 760 may reduce heat loss from the coiled piping and fluids inside the coiled piping. In some embodiments, coiled piping 758 has a diameter between 2' (about 0.6 m) and 4' (about 1.2 m) to accommodate up to about 30' (about 9.1 m) of expansion in piping 754.

[1312] FIG. 177 depicts a portion of piping 754 in overburden 400 after thermal expansion of the piping has occurred. Casing 398 has a large diameter to accommodate buckling of piping 754. Insulating cement 740 may be between overburden 400 and casing 398. Thermal expansion of piping 754 causes helical or sinusoidal buckling of the piping. The helical or sinusoidal buckling of piping 754 accommodates the thermal expansion of the piping, including the horizontal piping adjacent to the treatment area being heated. As depicted in FIG. 178, piping 754 may be more than one conduit positioned in large diameter casing 398. Having piping 754 as multiple conduits allows for accommodation of thermal expansion of all of the piping in the formation without increasing the pressure drop of the fluid flowing through piping in overburden 400.

[1313] In some embodiments, thermal expansion of subsurface piping is translated up to the wellhead. Expansion may be accommodated by one or more sliding seals at the wellhead. The seals may include Grafoil® gaskets, Stellite® gaskets, and/or Nitronic® gaskets. In some embodiments, the seals include seals available from BST Lift Systems, Inc. (Ventura, California, U.S.A.).

[1314] FIG. 179 depicts a representation of wellhead 392 with sliding seal 728. Wellhead 392 may include a stuffing box and/or other pressure control equipment. Circulated fluid may pass through conduit 742. Conduit 742 may be at least partially surrounded by insulated conduit 722. The use of insulated conduit 722 may obviate the need for a high temperature sliding seal and the need to seal against the heat transfer fluid. Expansion of conduit 742 may be handled at the surface with expansion loops, bellows, coiled or spooled pipe, and/or sliding joints. In some embodiments, packers 762 between insulated conduit 722 and casing 398 seal the wellbore

against formation pressure and hold gas for additional insulation. Packers 762 may be inflatable packers and/or polished bore receptacles. In certain embodiments, packers 762 are operable up to temperatures of about 600 °C. In some embodiments, packers 762 include seals available from BST Lift Systems, Inc. (Ventura, California, U.S.A.).

[1315] In some embodiments, thermal expansion of subsurface piping is handled at the surface with a slip joint that allows the heat transfer fluid conduit to expand out of the formation to accommodate the thermal expansion. Hot heat transfer fluid may pass from a fixed conduit into the heat transfer fluid conduit in the formation. Return heat transfer fluid from the formation may pass from the heat transfer fluid conduit into the fixed conduit. A sliding seal between the fixed conduit and the piping in the formation, and a sliding seal between the wellhead and the piping in the formation, may accommodate expansion of the heat transfer fluid conduit at the slip joint.

[1316] FIG. 180 depicts a representation of a system where heat transfer fluid in conduit 742 is transferred to or from fixed conduit 764. Insulating sleeve 722 may surround conduit 742. Sliding seal 728 may be between insulated sleeve 722 and wellhead 392. Packers between insulating sleeve 722 and casing 398 may seal the wellbore against formation pressure. Heat transfer fluid seals 790 may be positioned between a portion of fixed conduit 764 and conduit 742. Heat transfer fluid seals 790 may be secured to fixed conduit 764. The resulting slip joint allows insulating sleeve 722 and conduit 742 to move relative to wellhead 392 to accommodate thermal expansion of the piping positioned in the formation. Conduit 742 is also able to move relative to fixed conduit 764 in order to accommodate thermal expansion. Heat transfer fluid seals 790 may be uninsulated and spatially separated from the flowing heat transfer fluid to maintain the heat transfer fluid seals at relatively low temperatures.

[1317] In some embodiments, thermal expansion is handled at the surface with a slip joint where the heat transfer fluid conduit is free to move and the fixed conduit is part of the wellhead. FIG. 181 depicts a representation of a system where fixed conduit 764 is secured to wellhead 392. Fixed conduit 764 may include insulating sleeve 722. Heat transfer fluid seals 790 may be coupled to an upper portion of conduit 742. Heat transfer fluid seals 790 may be uninsulated and spatially separated from the flowing heat transfer fluid to maintain the heat transfer fluid seals at relatively low temperatures. Conduit 742 is able to move relative to fixed conduit 764 without the need for a sliding seal in wellhead 392.

[1318] FIG. 182 depicts an embodiment of seals 790. Seals 790 may include seal stack 766 attached to packer body 768. Packer body 768 may be coupled to conduit 742 using packer setting slips 770 and packer insulation seal 772. Seal stack 766 may engage polished portion 774 of conduit 764. In some embodiments, cam rollers 776 are used to provide support to seal stack

766. For example, if side loads are too large for the seal stack. In some embodiments, wipers 778 are coupled to packer body 768. Wipers 778 may be used to clean polished portion 774 as conduit 764 is inserted through seal 790. Wipers 778 may be placed on the upper side of seals 790, if needed. In some embodiments, seal stack 766 is loaded for better contact using a bow spring or other preloaded means to enhance compression of the seals.

[1319] In some embodiments, seals 790 and conduit 764 are run together into conduit 742. Locking mechanisms such as mandrels may be used to secure the seals and the conduits in place. FIG. 183 depicts an embodiment of seals 790, conduit 742, and conduit 764 secured in place with locking mechanisms 780. Locking mechanisms 780 include insulation seals 782 and locking slips 784. Locking mechanisms 780 may be activated as seals 790 and conduit 764 enter into conduit 742.

[1320] As locking mechanisms 780 engage a selected portion of conduit 742, springs in the locking mechanisms are activated and open and expose insulations seals 782 against the surface of conduit 742 just above locking slips 784. Locking mechanisms 780 allow insulations seals 782 to be retracted as the assembly is moved into conduit 742. The insulation seals are opened and exposed when the profile of conduit 742 activates the locking mechanisms.

[1321] Pins 786 secure locking mechanisms 780, seals 790, conduit 742, and conduit 764 in place. In certain embodiments, pins 786 unlock the assembly after a selected temperature to allow movement (travel) of the conduits. For example, pins 786 may be made of materials that thermally degrade (for example, melt) above a desired temperature.

[1322] In some embodiments, locking mechanisms 780 are set in place using soft metal seals (for example, soft metal friction seals commonly used to set rod pumps in thermal wells). FIG. 184 depicts an embodiment with locking mechanisms 780 set in place using soft metal seals 788. Soft metal seals 788 work by collapsing against a reduction in the inner diameter of conduit 742. Using metal seals may increase the lifetime of the assembly versus using elastomeric seals.

[1323] In certain embodiments, lift systems are coupled to the piping of a heater that extends out of the formation. The lift systems may lift portions of the heater out of the formation to accommodate thermal expansion. FIG. 185 depicts a representation of u-shaped wellbore 490 with heater 412 positioned in the wellbore. Wellbore 490 may include casings 398 and lower seals 792. Heater 412 may include insulated portions 794 with heater portion 796 adjacent to treatment area 730. Moving seals 790 may be coupled to an upper portion of heater 412. Lifting systems 798 may be coupled to insulated portions 794 above wellheads 392. A non-reactive gas (for example, nitrogen and/or carbon dioxide) may be introduced in subsurface annular region 800 between casings 398 and insulated portions 794 to inhibit gaseous formation fluid from rising to wellhead 392 and to provide an insulating gas blanket. Insulated portions 794 may be

conduit-in-conduits with the heat transfer fluid of the circulation system flowing through the inner conduit. The outer conduit of each insulated portion 794 may be at a substantially lower temperature than the inner conduit. The lower temperature of the outer conduit allows the outer conduits to be used as load bearing members for lifting heater 412. Differential expansion between the outer conduit and the inner conduit may be mitigated by internal bellows and/or by sliding seals.

[1324] Lifting systems 798 may include hydraulic lifters, powered coiled tubing rigs, and/or counterweight systems capable of supporting heater 412 and moving insulated portions 794 into or out of the formation. When lifting systems 798 include hydraulic lifters, the outer conduits of insulated portions 794 may be kept cool at the hydraulic lifters by dedicated slick transition joints. The hydraulic lifters may include two sets of slips. A first set of slips may be coupled to the heater. The hydraulic lifters may maintain a constant pressure against the heater for the full stroke of the hydraulic cylinder. A second set of slips may periodically be set against the outer conduit while the stroke of the hydraulic cylinder is reset. Lifting systems 798 may also include strain gauges and control systems. The strain gauges may be attached to the outer conduit of insulated portions 794, or the strain gauges may be attached to the inner conduits of the insulated portions below the insulation. Attaching the strain gauges to the outer conduit may be easier and the attachment coupling may be more reliable.

[1325] Before heating begins, set points for the control systems may be established by using lifting systems 798 to lift heater 412 such that portions of the heater contact casing 398 in the bend portions of wellbore 490. The strain when heater 412 is lifted may be used as the set point for the control system. In other embodiments, the set point is chosen in a different manner. When heating begins, heater portion 796 will begin expanding and some of the heater section will advance horizontally. If the expansion forces portions of heater 412 against casing 398, the weight of the heater will be supported at the contact points of insulated portions 794 and the casing. The strain measured by lifting system 798 will go towards zero. Additional thermal expansion may cause heater 412 to buckle and fail. Instead of allowing heater 412 to press against casing 398, hydraulic lifters of lifting systems 798 may move sections of insulated portions 794 upwards and out of the formation to keep the heater against the top of the casing. The control systems of lifting systems 798 may lift heater 412 to maintain the strain measured by the strain gauges near the set point value. Lifting system 798 may also be used to reintroduce insulated portions 794 into the formation when the formation cools to avoid damage to heater 412 during thermal contraction.

[1326] In certain embodiments, thermal expansion of the heater is completed in a relatively short time frame. In some embodiments, the position of the heater is fixed relative to the wellbore

after thermal expansion is completed. The lifting systems may be removed from the heaters and used on other heaters that have not yet been heated. Lifting systems may be reattached to the heaters when the formation is cooled to accommodate thermal contraction of the heaters.
In some embodiments, the lifting systems are controlled based on the hydraulic pressure of the lifters. Changes in the tension of the pipe may result in a change in the hydraulic pressure. The control system may maintain the hydraulic pressure substantially at a set hydraulic pressure to provide accommodation of thermal expansion of the heater in the formation.

[1327] In certain embodiments, the circulation system uses a liquid to heat the formation. The use of liquid heat transfer fluid may allow for high overall energy efficiency for the system as compared to electrical heating or gas heaters due to the high energy efficiency of heat supplies used to heat the liquid heat transfer fluid. If furnaces are used to heat the liquid heat transfer fluid, the carbon dioxide footprint of the process may be reduced as compared to electrically heating or using gas burners positioned in wellbores due to the efficiencies of the furnaces. If nuclear power is used to heat the liquid heat transfer fluid, the carbon dioxide footprint of the process may be significantly reduced or even eliminated. The surface facilities for the heating system may be formed from commonly available industrial equipment in simple layouts. Using commonly available equipment in simple layouts may increase the overall reliability of the system.

[1328] In certain embodiments, the liquid heat transfer fluid is a molten salt or other liquid that has the potential to solidify if the temperature is below a selected temperature. A secondary heating system may be needed to ensure that heat transfer fluid remains in liquid form and that the heat transfer fluid is at a temperature that allows the heat transfer fluid to flow through the heaters from the circulation system. In certain embodiments, the secondary heating system heats the heater and/or the heat transfer fluid to a temperature that is sufficient to melt and ensure flowability of the heat transfer fluid instead of heating to a higher temperature. The secondary heating system may only be needed for a short period of time during startup and/or re-startup of the fluid circulation system. In some embodiments, the secondary heating system is removable from the heater. In some embodiments, the secondary heating system does not have an expected lifetime on the order of the life of the heater.

[1329] In certain embodiments, molten salt is used as the heat transfer fluid. Insulated return storage tanks receive return molten salt from the formation. Temperatures in the return storage tanks may be, for example, in the vicinity of about 350 °C. Pumps may move the molten salt from the return storage tanks to furnaces. Each of the pumps may need to move between 4 kg/s and 30 kg/s of the molten salt. Each furnace may provide heat to the molten salt. Exit temperatures of the molten salt from the furnaces may be about 550 °C. The molten salt may

pass from the furnaces to insulated feed storage tanks through piping. Each feed storage stank may supply molten salt to, for example, 50 or more piping systems that enter into the formation. The molten salt flows through the formation and to the return storage tanks. In certain embodiments, the furnaces have efficiencies that are 90% or greater. In certain embodiments, heat loss to the overburden is 8% or less.

[1330] In some embodiments, the heaters for the circulation systems include insulation along the lengths of the heaters, including portions of the heaters that are used to heat the treatment area. The insulation may facilitate insertion of the heaters into the formation. The insulation adjacent to portions used to heat the treatment area may be sufficient to provide insulation during preheating, but may decompose at temperatures produced by steady state circulation of the heat transfer fluid. In some embodiments, the insulation layer changes the emissivity of the heater to inhibit radiative heat transfer from the heater. After decomposition of the insulation, the emissivity of the heater may promote radiative heat transfer to the treatment area. The insulation may reduce the time needed to raise the temperature of the heaters and/or the heat transfer fluid in the heaters to temperatures sufficient to ensure melt and flowability of the heat transfer fluid. In some embodiments, the insulation adjacent to portions of the heaters that will heat the treatment area may include polymer coatings. In certain embodiments, insulation of portions of the heaters adjacent to the overburden is different than the insulation of the heaters adjacent to the portions of the heaters used to heat the treatment area. The insulation of the heaters adjacent to the overburden may have an expected lifetime equal to or greater than the lifetime of the heaters.

[1331] In some embodiments, degradable insulation material (for example, a polymer foam) may be introduced into the wellbore after or during placement of the heater. The degradable insulation may provide insulation adjacent to the portions of the heaters used to heat the treatment area during preheating. The liquid heat transfer fluid used to heat the treatment area may raise the temperature of the heater sufficiently enough to degrade and eliminate the insulation layer.

[1332] In some embodiments, the secondary heating system may electrically heat the heaters of the fluid circulation system. In some embodiments, electricity is applied directly to the heat transfer fluid conduit to resistively heat the heat transfer fluid conduit. Directly heating the heat transfer fluid conduit may require large current because of the relatively low resistance of the heat transfer fluid conduit. In some embodiments, a return current path is needed for the heat transfer fluid conduit.

[1333] In some embodiments, the heat transfer fluid conduit includes ferromagnetic material that allows the effective resistance of the heat transfer fluid conduit to be higher due to skin effect

heating when time-varying current is applied to the heat transfer fluid conduit. For example, the heat transfer fluid conduit may be a steel with between about 9% and about 13% by weight chromium (for example, as 410 stainless steel). A return current path may be needed for the ferromagnetic material.

[1334] In certain embodiments, resistively heating the heater requires special considerations. Wellheads may need to include isolation flanges to ensure that current travels down the subsurface conduits and not through the surface pipe manifolds. Also, casings in the formation may need to be made of a non-ferromagnetic material (for example, non-ferromagnetic high manganese content steel, fiberglass, or carbon fiber) to inhibit induction current heating of the casing and/or the surrounding formation. In some embodiments, the overburden section of the heater is a conduit-in-conduit configuration with a thermal barrier between the conduits. The thermal barrier may act as insulation to limit the amount of heat transferred to the inner conduit and the molten salt. Making the outer conduit of a non-ferromagnetic material may allow for distribution of current between the inner conduit and the outer conduit to adequately heat the inner conduit and salt. In some embodiments, electrically conductive centralizers are located between the casing and the heater.

[1335] FIG. 186 depicts a side view representation of an embodiment of a system for heating a portion of a formation using a circulated fluid system and/or electrical heating. Wellheads 392 of heaters 412 may be coupled to heat transfer fluid circulation system 706 by piping. Wellheads 392 may also be coupled to electrical power supply system 802. In some embodiments, heat transfer fluid circulation system 706 is disconnected from the heaters when electrical power is used to heat the formation. In some embodiments, electrical power supply system 802 is disconnected from the heaters when heat transfer fluid circulation system 706 is used to heat the formation.

[1336] Electrical power supply system 802 may include transformer 414 and cables 804, 806. In certain embodiments, cables 804, 806 are capable of carrying high currents with low losses. For example, cables 804, 806 may be thick copper or aluminum conductors. The cables may also have thick insulation layers. In some embodiments, cable 804 and/or cable 806 may be superconducting cables. The superconducting cables may be cooled by liquid nitrogen. Superconducting cables are available from Superpower, Inc. (Schenectady, New York, U.S.A.). Superconducting cables may minimize power loss and/or reduce the size of the cables needed to couple transformer 414 to the heaters. In some embodiments, cables 804, 806 are made of carbon nanotubes. Cables 804, 806 may be electrically coupled to heaters 412 to resistively heat the heaters.

[1337] In some embodiments, insulated conductors that resistively heat are used to preheat and/or ensure heat transfer flow in the heaters of a fluid circulation system. FIG. 187 depicts a representation of heater 412 that may initially be resistively heated with the return current path provided by insulated conductor 410. Electrical connection between a lead of transformer 414 and heater 412 may be made near a first side of the heater. The other lead of transformer 414 may be electrically coupled to insulated conductor 410. Electrical connection 808 between heater 412 and insulated conductor 410 may be made on an opposite side of heater from transformer 414 to complete the electrical circuit. FIG. 188 depicts a representation of heater 412 that may initially be resistively heated with the return current path provided by two insulated conductors 410. Transformers 414 may be located on each side of heater 412. Leads from transformers 414 may be electrically coupled to heater 412. The other leads for transformers 414 may be electrically coupled to insulated conductors 410. Electrical connections 808 between insulated conductors 410 and heater 412 may be made near the center of the heater to complete the electrical circuits. Insulated conductors 410 depicted in FIG. 187 and FIG. 188 may be good electrical conductors that provide little or no resistive heating. Insulated conductors 410 may be coupled to the inside of heaters 412 as depicted, or the insulated conductors may be positioned outside of the heaters.

[1338] FIG. 189 depicts a representation of insulated conductors 410 used to resistively heat heaters 412 of a circulated fluid heating system. Insulated conductors 410 may be coupled to transformer 414 in a three phase configuration. Lead-in and lead-out portions of insulated conductors may be good electrical conductors that provide little or no resistive heating. Portions of insulated conductors 410 coupled to or positioned in heaters 412 may include material that resistively heats to temperatures sufficient to heat the heat transfer fluid in the heaters to a temperature sufficient to allow flow of the heat transfer fluid. In some embodiments, the material is ferromagnetic and the insulated conductors operate as temperature limited heaters. The Curie point temperature limit or phase transition temperature limit of the ferromagnetic material may allow the insulated conductors to reach temperatures above but relatively close to the temperature needed to ensure melt and flowability of heat transfer fluid in heaters 412.

[1339] FIG. 190 depicts insulated conductor 410 positioned in heater 412. Heater 412 is piping of the circulation system positioned in the formation. Electricity applied to insulated conductor 410 resistively heats the insulated conductor. The generated heat transfers to heater 412 and heat transfer fluid in the heater. In some embodiments, the insulated conductors may be strapped to the outside of the heaters instead of being placed inside of the heaters. Insulated conductor 410 may be a relatively thin mineral insulated conductor positioned in a relatively large diameter piping as shown. In some embodiments, insulated conductors positioned in the heaters may be

placed inside of a protective sleeve. For example, the insulated conductor may have an outer diameter of about 0.6 inches and placed inside a 1 inch tube or pipe that is placed in the 5 inch heater pipe.

[1340] In some embodiments, insulated conductors positioned inside or outside heaters used with a circulated fluid heating system may provide current that is used to cause inductive heating. The current flowing through the insulated conductors may be used to induce currents in the heater so that the heater resistively heats. In some embodiments, the insulated conductors may be wrapped with a coil that is inductively heated. The coil may be made of a material that has a Curie temperature limit or phase transition temperature limit slightly higher than the temperature needed to ensure melt and flowability of heat transfer fluid in the heaters.

[1341] In some embodiments, insulated conductors used as current paths or as electrical heaters may be removable from heaters used for circulating heat transfer fluid. After heat transfer fluid circulation in a heater is initiated and stabilizes, the heat transfer fluid will heat the adjacent formation to temperatures above the temperature needed to ensure melt and flowability of the heat transfer fluid. The heat of the formation and the heat of the heat transfer fluid may be sufficient to ensure melt and flowability of the heat transfer fluid should the circulation system temporarily be interrupted (for example, for a day, a week, or a month). For heaters with the insulated conductor positioned in the heater, the insulated conductors may be pulled out of the heater through seals in the wellhead that allow for electrical connection to the insulated conductors. The insulated conductors may be coiled and reused in heaters that have not been preheated. Should it be necessary, insulated conductor heaters may be reintroduced into the heaters.

[1342] In some embodiments of circulation systems that use molten salt or another liquid as the heat transfer fluid, the heater may be a single conduit in the formation. The conduit may be preheated to a temperature sufficient to ensure flowability of the heat transfer fluid. In some embodiments, a secondary heat transfer fluid is circulated through the conduit to preheat the conduit and/or the formation adjacent to the conduit. After the temperature of the conduit and/or the formation adjacent to the conduit is sufficiently hot, the secondary fluid may be flushed from the conduit and the heat transfer fluid may be circulated through the pipe.

[1343] In some embodiments, aqueous solutions of the salt composition (for example, $Li:Na:K:NO_3$) that is to be used as the heat transfer fluid are used to preheat the conduit. A temperature of the secondary heat transfer fluid may be below or equal to a temperature of a subsurface outlet of the wellhead.

[1344] In some embodiments, the secondary heat transfer fluid (for example, water) is heated to a temperature ranging from 0 °C to about 95 °C or up to the boiling point of the secondary heat

transfer fluid. The salt composition may be added to the secondary heat transfer fluid while in a storage tank of the circulation systems. The composition of the salt and/or the pressure of the system may be adjusted to inhibit boiling of the aqueous solution as the temperature is increased. When the conduit is preheated to a temperature sufficient to ensure flowability of the molten salt, the remaining water may be removed from the aqueous solution to leave only the molten salt. The water may be removed by evaporation while the salt solution is in a storage tank of the circulation system. In some embodiments, the temperature of the molten salt solution is raised to above 100 °C. When the conduit is preheated to a temperature sufficient to ensure flowability of the molten salt, substantially or all of the remaining secondary heat transfer fluid (for example, water) may be removed from the salt solution to leave only the molten salt. In some embodiments, the temperature of the molten salt solution during the evaporation process ranges from 100 °C to 250°C.

[1345] Upon completion of the in situ heat treatment process, the molten salt may be cooled and water added (for example, water may be sprayed into the storage tank) to the salt to form another aqueous solution. In some embodiments, the molten salt may be cooled by circulating the molten salt solution through one or more heat exchangers. The aqueous solution may be transferred to another treatment area and the process continued. In some embodiments, sufficient water may be added and circulated to the storage system until the molten salt solution is below the required level for abandonment. The excess water solution may be transferred to another tank for disposal and/or transferred to another treatment area. Use of tertiary molten salts as aqueous solutions facilitates transportation of the solution and allows than one section of a formation to be treated with the same salt.

[1346] In some embodiments of circulation systems that use molten salt or other liquid as the heat transfer fluid, the heater may have a conduit-in-conduit configuration. The liquid heat transfer fluid used to heat the formation may flow through a first passageway through the heater. A secondary heat transfer fluid may flow through a second passageway through the conduit-in-conduit heater for preheating and/or for flow assurance of the liquid heat transfer fluid. After the heater is raised to a temperature sufficient to ensure continued flow of heat transfer fluid through the heater, a vacuum may be drawn on the passageway for the secondary heat transfer fluid to inhibit heat transfer from the first passageway to the second passageway. In some embodiments, the passageway for the secondary heat transfer fluid is filled with insulating material and/or is otherwise blocked. The passageways in the conduit of the conduit-in-conduit heater may include the inner conduit and the annular region between the inner conduit and the outer conduit. In some embodiments, one or more flow switchers are used to change the flow in the conduit-in-conduit heater from the inner conduit to the annular region and/or vice versa.

[1347] FIG. 191 depicts a cross-sectional view of an embodiment of conduit-in-conduit heater 412 for a heat transfer circulation heating system adjacent to treatment area 730. Heater 412 may be positioned in wellbore 490. Heater 412 may include outer conduit 810 and inner conduit 812. During normal operation of heater 412, liquid heat transfer fluid may flow through annular region 814 between outer conduit 810 and inner conduit 812. During normal operation, fluid flow through inner conduit 812 may not be needed.

[1348] During preheating and/or for flow assurance, a secondary heat transfer fluid may flow through inner conduit 812. The secondary fluid may be, but is not limited to, air, carbon dioxide, exhaust gas, and/or a natural or synthetic oil (for example, DowTherm A, Syltherm, or Therminol 59), room temperature molten salts (for example, $NaCl_2$-$SrCl_2$, VCl_4, $SnCl_4$, or $TiCl_4$), high pressure liquid water, steam, or room temperature molten metal alloys (for example, a K-Na eutectic or a Ga-In-Sn eutectic). In some embodiments, outer conduit 810 is heated by the secondary heat transfer fluid flowing through annular region 814 (for example, carbon dioxide or exhaust gas) before the heat transfer fluid that is used to heat the formation is introduced into the annular region. If exhaust gas or other high temperature fluid is used, another heat transfer fluid (for example, water or steam) may be passed through the heater to reduce the temperature below the upper working temperature limit of the liquid heat transfer fluid. The secondary heat transfer fluid may be displaced from the annular region when the liquid heat transfer fluid is introduced into the heater. The secondary heat transfer fluid in inner conduit 812 may be the same fluid or a different fluid than the secondary fluid used to preheat outer conduit 810 during preheating. Using two different secondary heat transfer fluids may help in the identification of integrity problems in heater 412. Any integrity problems may be identified and fixed before the use of the molten salt is initiated.

[1349] In some embodiments, the secondary heat transfer fluid that flows through annular region 814 during preheating is an aqueous mixture of the salt to be used during normal operation. The salt concentration may be increased periodically to increase temperature while remaining below the boiling temperature of the aqueous mixture. The aqueous mixture may be used to raise the temperature of outer conduit 810 to a temperature sufficient to allow the molten salt to flow in annular region 814. When the temperature is reached, the remaining water in the aqueous mixture may evaporate out of the mixture to leave the molten salt. The molten salt may be used to heat treatment area 730.

[1350] In some embodiments, inner conduit 812 may be made of a relatively inexpensive material such as carbon steel. In some embodiments, inner conduit 812 is made of material that survives through an initial early stage of the heat treatment process. Outer conduit 810 may be

made of material resistant to corrosion by the molten salt and formation fluid (for example, P91 steel).

[1351] For a given mass flow rate of liquid heat transfer fluid, heating the treatment area using liquid heat transfer fluid flowing in annular region 814 between outer conduit 810 and inner conduit 812 may have certain advantages over flowing the liquid heat transfer fluid through a single conduit. Flowing secondary heat transfer fluid through inner conduit 812 may pre-heat heater 412 and ensure flow when liquid heat transfer fluid is first used and/or when flow needs to be restarted after a stop of circulation. The large outer surface area of outer conduit 810 provides a large surface area for heat transfer to the formation while the amount of liquid heat transfer fluid needed for the circulation system is reduced because of the presence of inner conduit 812. The circulated liquid heat transfer fluid may provide a better power injection rate distribution to the treatment area due to increased velocity of the liquid heat transfer fluid for the same mass flow rate. Reliability of the heater may also be improved.

[1352] In some embodiments, the heat transfer fluid (molten salt) may thicken and flow of the heat transfer fluid through outer conduit 810 and/or inner conduit 812 is slowed and/or impaired. Selectively heating various portions of inner conduit 812 may provide sufficient heat to various parts of the heater 412 to increase flow of the heat transfer fluid through the heater. Portions of heater 412 may include ferromagnetic material (for example, insulated conductors) to allow current to be passed along selected portions of the heater. Resistively heating inner conduit 812 transfers sufficient heat to thickened heat transfer fluid in outer conduit 810 and/or inner conduit 812 to lower the viscosity of the heat transfer fluid such that increased flow, as compared to flow prior to heating of the molten salt, through the conduits is obtained. Using time-varying current allows current to be passed along the inner conduit without passing current through the heat transfer fluid.

[1353] FIG. 192 depicts a schematic for heating various portions of heater 412 to restart flow of thickened or immobilized heat transfer fluid (for example, a molten salt) in the heater. In certain embodiments, portions of inner conduit 812 and/or outer conduit 810 include ferromagnetic materials surrounded by thermal insulation. Thus, these portions of inner conduit 812 and/or outer conduit 810 may be insulated conductors 410. Insulated conductors 410 may operate as temperature limited heaters or skin-effect heaters. Because of the skin-effect of insulated conductors 410, electrical current provided to the insulated conductors remains confined to inner conduit 812 and/or outer conduit 810 and does not flow through the heat transfer fluid located in the conduits.

[1354] In certain embodiments, insulated conductors 410 are positioned along a selected length of inner conduit 812 (for example, the entire length of the inner conduit or only the overburden

portion of the inner conduit). Applying electricity to inner conduit 812 generates heat in insulated conductors 410. The generated heat may heat thickened or immobilized heat transfer fluid along the selected length of the inner conduit. The generated heat may heat the heat transfer fluid both inside the inner conduit and in the annulus between the inner conduit and outer conduit 810. In certain embodiments, inner conduit 812 only includes insulated conductors 410 positioned in the overburden portion of the inner conduit. These insulated conductors selectively generate heat in the overburden portions of inner conduit 812. Selectively heating the overburden portion of inner conduit 812 may transfer heat to thickened heat transfer fluid and restart flow in the overburden portion of the inner conduit. Such selective heating may increase heater life and minimize electrical heating costs by concentrating heat in the region most likely to encounter thickening or immobilization of the heat transfer fluid.

[1355] In certain embodiments, insulated conductors 410 are positioned along a selected length of outer conduit 810 (for example, the overburden portion of the outer conduit). Applying electricity to outer conduit 810 generates heat in insulated conductors 410. The generated heat may selectively heat the overburden portions of the annulus between inner conduit 812 and outer conduit 810. Sufficient heat may be transferred from outer conduit 810 to lower the viscosity of the thickened heat transfer fluid to allow unimpaired flow of the molten salt in the annulus.

[1356] In certain embodiments, having a conduit-in-conduit heater configuration allows flow switchers to be used that change the flow of heat transfer fluid in the heater from flow through the annular region between the outer conduit and the inner conduit, when flow is adjacent to the treatment area, to flow through the inner conduit, when flow is adjacent to the overburden. FIG. 193 depicts a schematic representation of conduit-in-conduit heaters 412 that are used with fluid circulation systems 706, 706' to heat treatment area 730. In certain embodiments, heaters 412 include outer conduit 810, inner conduit 812, and flow switchers 816. Fluid circulation systems 706, 706' provide heated liquid heat transfer fluid to wellheads 392. The direction of flow of liquid heat transfer fluid is indicated by arrows 818.

[1357] Heat transfer fluid from fluid circulation system 706 passes through wellhead 392 to inner conduit 812. The heat transfer fluid passes through flow switcher 816, which changes the flow from inner conduit 812 to the annular region between outer conduit 810 and the inner conduit. The heat transfer fluid then flows through heater 412 in treatment area 730. Heat transfer from the heat transfer fluid provides heat to treatment area 730. The heat transfer fluid then passes through second flow switcher 816', which changes the flow from the annular region back to inner conduit 812. The heat transfer fluid is removed from the formation through second wellhead 392' and is provided to fluid circulation system 706'. Heated heat transfer fluid from fluid circulation system 706' passes through heater 412' back to fluid circulation system 706.

[1358] Using flow switchers 816 to pass the fluid through the annular region while the fluid is adjacent to treatment area 730 promotes increased heat transfer to the treatment area due in part to the large heat transfer area of outer conduit 810. Using flow switchers 816 to pass the fluid through the inner conduit when adjacent to overburden 400 may reduce heat losses to the overburden. Additionally, heaters 412 may be insulated adjacent to overburden 400 to reduce heat losses to the formation.

[1359] FIG. 194 depicts a cross-sectional view of an embodiment of a conduit-in-conduit heater 412 adjacent to overburden 400. Insulation 820 may be positioned between outer conduit 810 and inner conduit 812. Liquid heat transfer fluid may flow through the center of inner conduit 812. Insulation 820 may be a highly porous insulation layer that inhibits radiation at high temperatures (for example, temperatures above 500 °C) and allows flow of a secondary heat transfer fluid during preheating and/or flow assurance stages of heating. During normal operation, flow of fluid through the annular region between outer conduit 810 and inner conduit 812 adjacent to overburden 400 may be stopped or inhibited.

[1360] Insulating sleeve 722 may be positioned around outer conduit 810. Insulating sleeves 722 on each side of a u-shaped heater may be securely coupled to outer conduit 810 over a long length when the system is not heated so that the insulating sleeves on each side of the u-shaped wellbore are able to support the weight of the heater. Insulating sleeve 722 may include an outer member that is a structural member that allows heater 412 to be lifted to accommodate thermal expansion of the heater. Casing 398 may surround insulating sleeve 722. Insulating cement 740 may couple casing 398 to overburden 400. Insulating cement 740 may be a low thermal conductivity cement that reduces conductive heat losses. For example, insulating cement 740 may be a vermiculite/cement aggregate. A non-reactive gas may be introduced into gap 744 between insulating sleeve 722 and casing 398 to inhibit formation fluid from rising in the wellbore and/or to provide an insulating gas blanket.

[1361] FIG. 195 depicts a schematic of an embodiment of circulation system 706 that supplies liquid heat transfer fluid to conduit-in-conduit heaters positioned in the formation (for example, the heaters depicted in FIG. 193). Circulation system 706 may include heat supply 708, compressor 822, heat exchanger 824, exhaust system 826, liquid storage tank 828, fluid movers 714 (for example, pumps), supply manifold 830, return manifold 832, and secondary heat transfer fluid circulation system 834. In certain embodiments, heat supply 708 is a furnace. Fuel for heat supply 708 may be supplied through fuel line 836. Control valve 838 may regulate the amount of fuel supplied to heat supply 708 based on the temperature of hot heat transfer fluid as measured by temperature monitor 840.

[1362] Oxidant for heat supply 708 may be supplied through oxidant line 842. Exhaust from heat supply 708 may pass through heat exchanger 824 to exhaust system 826. Oxidant from compressor 822 may pass through heat exchanger 824 to be heated by the exhaust from heat supply 708.

[1363] In some embodiments, valve 844 may be opened during preheating and/or during start-up of fluid circulation to the heaters to supply secondary heat transfer fluid circulation system 834 with a heating fluid. In some embodiments, exhaust gas is circulated through the heaters by secondary heat transfer fluid circulation system 834. In some embodiments, the exhaust gas passes through one or more heat exchangers of secondary heat transfer fluid circulation system 834 to heat fluid that is circulated through the heaters.

[1364] During preheating, secondary heat transfer fluid circulation system 834 may supply secondary heat transfer fluid to the inner conduit of the heaters and/or to the annular region between the inner conduit and the outer conduit. Line 846 may provide secondary heat transfer fluid to the part of supply manifold 830 that supplies fluid to the inner conduits of the heaters. Line 848 may provide secondary heat transfer fluid to the part of supply manifold 830 that supplies fluid to the annular regions between the inner conduits and the outer conduits of the heaters. Line 850 may return secondary heat transfer fluid from the part of the return manifold 832 that returns fluid from the inner conduits of the heaters. Line 852 may return secondary heat transfer fluid from the part of the return manifold 832 that returns fluid from the annular regions of the heaters. Valves 854 of secondary heat transfer fluid circulation system 834 may allow or stop secondary heat transfer flow to or from supply manifold 830 and/or return manifold 832. During preheating, all valves 854 may be open. During the flow assurance stage of heating, valves 854 for line 846 and for line 850 may be closed, and valves 854 for line 848 and line 852 may be open. Liquid heat transfer fluid from heat supply 708 may be provided to the part of supply manifold 830 that supplies fluid to the inner conduits of the heaters during the flow assurance stage of heating. Liquid heat transfer fluid may return to liquid storage tank 828 from the portion of return manifold 832 that returns fluid from the inner conduits of the heaters. During normal operation, all valves 854 may be closed.

[1365] In some embodiments, secondary heat transfer fluid circulation system 834 is a mobile system. Once normal flow of heat transfer fluid through the heaters is established, the mobile secondary heat transfer fluid circulation system 834 may be moved and attached to another circulation system that has not been initiated.

[1366] During normal operation, liquid storage tank 828 may receive heat transfer fluid from return manifold 832. Liquid storage tank 828 may be insulated and heat traced. Heat tracing may include steam circulation system 856 that circulates steam through coils in liquid storage

tank 828. Steam passed through the coils maintains heat transfer fluid in liquid storage tank 828 at a desired temperature or in a desired temperature range.

[1367] Fluid movers 714 may move liquid heat transfer fluid from liquid storage tank 828 to heat supply 708. In some embodiments, fluid movers 714 are submersible pumps that are positioned in liquid storage tank 828. Having fluid movers 714 in storage tanks may keep the pumps at temperatures well within the operating temperature limits of the pumps. Also, the heat transfer fluid may function as a lubricant for the pumps. One or more redundant pump systems may be placed in liquid storage tank 828. A redundant pump system may be used if the primary pump system shuts down or needs to be serviced.

[1368] During start-up of heat supply 708, valves 858 may direct liquid heat transfer fluid to liquid storage tank. After preheating of a heater in the formation is completed, valves 858 may be reconfigured to direct liquid heat transfer fluid to the part of supply manifold 830 that supplies the liquid heat transfer fluid to the inner conduit of the preheated heater. Return liquid heat transfer fluid from the inner conduit of a preheated return conduit may pass through the part of return manifold 832 that receives heat transfer fluid that has passed through the formation and directs the heat transfer fluid to liquid storage tank 828.

[1369] To begin using fluid circulation system 706, liquid storage tank 828 may be heated using steam circulation system 856. The heat transfer fluid may be added to liquid storage tank 828. The heat transfer fluid may be added as solid particles that melt in liquid storage tank 828 or liquid heat transfer fluid may be added to the liquid storage tank. Heat supply 708 may be started, and fluid movers 714 may be used to circulate heat transfer fluid from liquid storage tank 828 to the heat supply and back. Secondary heat transfer fluid circulation system 834 may be used to heat heaters in the formation that are coupled to supply manifolds 830 and return manifolds 832. Supply of secondary heat transfer fluid to the portion of supply manifold 830 that feeds the inner conduits of the heaters may be stopped. The return of secondary heat transfer fluid from the portion of return manifold that receives heat transfer fluid from the inner conduits of the heaters may also be stopped. Heat transfer fluid from heat supply 708 may then be directed to the inner conduit of the heaters.

[1370] The heat transfer fluid may flow through the inner conduits of the heaters to flow switchers that change the flow of fluid from the inner conduits to the annular regions between the inner conduits and the outer conduits. The heat transfer fluid may then pass through flow switchers that change the flow back to the inner conduits. Valves coupled to the heaters may allow heat transfer fluid flow to the individual heaters to be started sequentially instead of having the fluid circulation system supply heat transfer fluid to all of the heaters at once.

[1371] Return manifold 832 receives heat transfer fluid that has passed through heaters in the formation that are supplied from a second fluid circulation system. Heat transfer fluid in return manifold 832 may be directed back into liquid storage tank 828.

[1372] During initial heating, secondary heat transfer fluid circulation system 834 may continue to circulate secondary heat transfer fluid through the portion of the heater not receiving the heat transfer fluid supplied from heat supply 708. In some embodiments, secondary heat transfer fluid circulation system 834 directs the secondary heat transfer fluid in the same direction as the flow of heat transfer fluid supplied from heat supply 708. In some embodiments, secondary heat transfer fluid circulation system 834 directs the secondary heat transfer fluid in the opposite direction to the flow of heat transfer fluid supplied from heat supply 708. The secondary heat transfer fluid may ensure continued flow of the heat transfer fluid supplied from heat supply 708. Flow of the secondary heat transfer fluid may be stopped when the secondary heat transfer fluid leaving the formation is hotter than the secondary heat transfer fluid supplied to the formation due to heat transfer with the heat transfer fluid supplied from heat supply 708. In some embodiments, flow of secondary heat transfer fluid may be stopped when other conditions are met, after a selected period of time.

[1373] FIG. 196 depicts a schematic representation of a system for providing and removing liquid heat transfer fluid to the treatment area of a formation using gravity and gas lifting as the driving forces for moving the liquid heat transfer fluid. The liquid heat transfer fluid may be a molten metal or a molten salt. Vessel 860 is elevated above heat exchanger 862. Heat transfer fluid from vessel 860 flows through heat transfer unit 862 to the formation by gravity drainage. In an embodiment, heat exchanger 862 is a tube and shell heat exchanger. Input stream 864 is a hot fluid (for example, helium) from nuclear reactor 866. Exit stream fluid 868 may be sent as a coolant stream to nuclear reactor 866. In some embodiments, the heat exchanger is a furnace, solar collector, chemical reactor, fuel cell, and/or other high temperature source able to supply heat to the liquid heat transfer fluid.

[1374] Hot heat transfer fluid from heat exchanger 862 may pass to a manifold that provides heat transfer fluid to individual heater legs positioned in the treatment area of the formation. The heat transfer fluid may pass to the heater legs by gravity drainage. The heat transfer fluid may pass through overburden 400 to hydrocarbon containing layer 388 of the treatment area. The piping adjacent to overburden 400 may be insulated. Heat transfer fluid flows downwards to sump 870.

[1375] Gas lift piping may include gas supply line 872 within conduit 874. Gas supply line 872 may enter sump 870. When lift chamber 876 in sump 870 fills to a selected level with heat transfer fluid, a gas lift control system operates valves of the gas lift system to lift the heat transfer fluid through the space between gas supply line 872 and conduit 874 to separator 878.

Separator 878 may receive heat transfer fluid and lifting gas from a piping manifold that transports the heat transfer fluid and lifting gas from the individual heater legs in the formation. Separator 878 separates the lift gas from the heat transfer fluid. The heat transfer fluid is sent to vessel 860.

[1376] Conduits 874 from sumps 870 to separator 878 may include one or more insulated conductors or other types of heaters. The insulated conductors or other types of heaters may be placed in conduits 874 and/or be strapped or otherwise coupled to the outside of the conduits. The heaters may inhibit densification or solidification of the heat transfer fluid in conduits 874 during gas lift from sump 870.

[1377] Using molten salts as a heat transfer fluid for in situ heat treatment process has many advantages. Many molten salts will react with certain hydrocarbons, thus, if circulating molten salts are used to heat a portion of a treatment area, a leak in the system which allows molten salts to contact subsurface hydrocarbons may cause problems. Reaction of molten salts with hydrocarbons may disrupt heat transfer systems, decrease permeability in the treatment area, decrease hydrocarbon production, and/or impede the flow of hydrocarbons through at least a portion of the treatment area being heated by circulating molten salt heaters.

[1378] In some embodiments, electrical conductivity may be used to assess the inception, existence, and/or location of leaks in the heater using heat transfer fluids such as molten salts. A resistance across one or more conduits of, for example, a conduit-in-conduit heater may be monitored for any changes. Changes in the monitored resistance may indicate the inception and/or worsening of a leak in the conduit. The conduits forming the conduit-in-conduit heater may include a void in the walls forming the conduits. The void in the walls forming the conduit may include a thermal insulation material positioned in the void. If a breach forms in the conduit walls, heat transfer fluid may enter through the breach leaking through to the other side. Some heat transfer fluids, for example molten salts, leaking through the breach in the conduit may conduct electricity creating a short across the conduit wall. The electrical short created by the leaking molten salt may then modify the measured resistance across the conduit wall in which the breach has occurred.

[1379] In some embodiments, the electrical resistance of at least one of the conduits of the conduit-in-conduit heaters may be assessed. A presence of a leak in at least one of the conduits may be assessed based on the assessed resistance. The electrical resistance may be assessed intermittently or on a continuous basis. The electrical resistance may be assessed for either one or both conduits of the conduit-in-conduit heater. FIG. 197 depicts a schematic representation of an embodiment of vertical conduit-in-conduit heater 412 for use with a heat transfer fluid circulation system for heating a portion of a formation (for example, hydrocarbon layer 388).

The heat transfer fluid circulation system may provide heat transfer fluid 1430 to inlet conduit 716 of heater 412. The heat transfer fluid circulation system may receive heat transfer fluid 1430 from outlet conduit heat 718. One or more portions of conduits 716 and 718 may include insulation 820 positioned between the inner and outer walls of the conduits. Multiple breaches 1432 may occur in conduits 716 and 718 through which heat transfer fluid 1430 leaks.

[1380] In some embodiments, a location of a breach in the conduit may be assessed. The location may be assessed due to the fact that the relationship between the electrical resistance and the depth at which the breach has occurred is very linear as is demonstrated in FIGS. 198 and 199. FIG. 198 depicts a graphical representation of the relationship (line 1434) of the electrical resistance of an inner conduit of a conduit-in-conduit heater over a depth at which a breach has occurred in the inner conduit of the conduit-in-conduit heater. FIG. 199 depicts a graphical representation of the relationship (line 1436) of the electrical resistance of an outer conduit of a conduit-in-conduit heater over a depth at which a breach has occurred in the outer conduit of the conduit-in-conduit heater. This linear relationship may allow the approximate depth of a breach in a conduit to be assessed and therefore the approximate location of the breach in the conduit. Once the location of a breach is assessed, options for dealing with the breach may be determined.

[1381] FIG. 200 depicts a graphical representation of the relationship of the electrical resistance of an inner conduit of a conduit-in-conduit heater (line 1438) and the salt block height (line 1440) over an amount of leaked molten salt. FIG. 201 depicts a graphical representation of the relationship of the electrical resistance of an outer conduit of a conduit-in-conduit heater (line 1442) and the salt block height (line 1444) over an amount of leaked molten salt. As demonstrated in FIGS. 200 and 201 a small leak in one or more of the conduits in the conduit-in-conduit heater may be detected. For example, a molten salt leak of as little as 0.038 liters may be detected by monitoring the electrical resistance across a wall of the conduit. FIGS. 200 and 201 also demonstrate (lines 1440 and 1444) that even a relatively small leak will fill a relatively large portion of the annulus space of the conduit-in-conduit heater. For example, 0.038 liters of leaked molten salt may fill approximately 2.04 m of the inner conduit or approximately 0.76 m of the outer conduit.

[1382] FIG. 202 depicts a graphical representation of the relationship (line 1446) of the electrical resistance of a conduit of a conduit-in-conduit heater once a breach forms over an average temperature of the molten salt. As FIG. 202 demonstrates, if a breach in one of the conduits of the conduit-in-conduit heater does occur the impact on the temperature is relatively small.

[1383] In some embodiments, a gas in combination with, for example, a gas detection system may be used to detect a breach, and subsequent leaks, in one or more conduits of a conduit-in-conduit heater. One or more gases may be dissolved in the heat transfer fluid, for example a

molten salt. The gas may be dissolved in the molten salt before the molten salt is transferred to the conduit-in-conduit heater (for example, in a storage tank used to store the molten salt). The gas may be dissolved in the molten salt as the molten salt is injected in the heater. The dissolved gas may circulate through the heater along with the molten salt.

[1384] In some embodiments, one or more of the gases may include an inert gas (for example, nitrogen, argon, helium, or mixtures thereof). In some embodiments, the gas detection system may include a pressure transducer or a gas analyzer. A breach in a conduit of the heater may result in a leak of at least some of the circulating molten salts in the annulus space of the conduit. Once the molten salt leaks in the annular space of the conduit, at least some of the gas dissolved in the molten salt may be released from the molten salt in the annular space of the conduit. The annular space may be under reduced pressure (for example, in order to provide more insulation value) and reduced temperature. The reduced pressure of the annular space may further facilitate the release of the dissolved gas from any molten salts which have leaked in the annular space. Table 6 shows the solubility of several inert gases including helium, argon, and nitrogen in molten nitrates. Solubility of the gas in the salt may generally scale substantially linearly with partial pressure according to Henry's Law.

TABLE 6

	T [°C]	**kH [mol/ml bar]**	**DH [kJ/mol]**
$He + NaNO_3$	332	1.86	13.4
	391	2.32	
	441	2.80	
$Ar + NaNO_3$	331	0.64	15.8
	410	0.90	
	440	1.04	
$N_2 + NaNO_3$	331	0.50	16.0
	390	0.64	
	449	0.84	
$He + LiNO_3$	270	1.51	
$Ar + LiNO_3$	273	0.91	14.0
$N_2 + LiNO_3$	277	0.73	

[1385] The gas released from the heater may be detected by the gas detection system. The gas detection system may be coupled to one or more openings in fluid communication with the annular space of the conduit. Heaters currently in use may have preexisting openings which may be adapted to accommodate the gas detection system. Heaters currently in use may be retrofitted for the currently described leak detection system. FIG. 203 depicts a schematic representation of an embodiment of vertical heater 412 for use with a heat transfer fluid circulation system for heating a portion of a formation (for example, hydrocarbon layer 388) which is coupled to an inert gas based leak detection system (not depicted).

[1386] In some embodiments, the gas detection system may be coupled to a plurality of heaters. Once a heater has formed a breach in one of the conduits, the heater in question may be identified by sequentially isolating each heater coupled to the gas detection system. In some embodiments, a leak detection system based upon detection of gases in annular spaces may not be able to assist in assessing the location of the breach (as the electrical resistance leak detection system may allow). In some embodiments, a leak detection system based upon detection of gases in annular spaces may not be able to assist in assessing the formation of breaches in one or more conduits along any horizontal portions.

[1387] In some embodiments, one or more portions of a conduit of a circulating molten salt system develops a leak. After a period of heating, coke may form and/or infiltrate in the conduit adjacent to the leak. Coke deposits in one or more conduits in a heater may lead to several problems (for example, hot spots and/or heater failure). In some embodiments, an oxidizing fluid may be provided to one or more portions of the conduit. Oxidizing fluid may include, for example, air or enriched air. Contact of the oxidizing fluid with coke may convert the coke in the conduit to products that may flow through the conduit.

[1388] In some embodiments, oxidizing fluid may be mixed with the molten salt before the molten salt is circulated through the heater in the formation. Mixing air with the molten salt may inhibit any significant coke formation in the conduits. For example, oxidizing fluid may be fixed with a molten salt in Heat transfer fluid circulation system 706. In some embodiments, oxidizing fluid may be provided to one or more conduits of a heater intermittently and/or as needed.

[1389] The use of circulating molten salts to heat underground hydrocarbon containing formations has many advantages relative to other known methods of heating a formation. It would be advantageous to be able to shut down a heating system using circulating molten salts in a more controlled manner. As opposed to other types of heating systems one cannot simply turn off a heat transfer fluid based heating system. Heat transfer fluid must be removed from the conduits of the conduit-in-conduit heaters during a shut-down procedure. When the heat transfer fluid is molten salt, removal of the salts presents different challenges. If the circulating pumps

are turned off the molten salt will begin to cool and solidify clogging the conduits. Due to the fact that salts are typically soluble in one or more solvents, one strategy for removing the salt from the heater conduits is to flush the conduits with an aqueous solution. However, flushing the conduits with an aqueous solution may take anywhere from days to months depending on the temperature of the formation. In some embodiments, secondary fluids (for example, fluids produced during in situ heat treatment and/or conversion processes) may be used to flush out salts from the conduits. Due to the typically higher boiling point of secondary fluids, removing remaining salts from the conduits may be accomplished faster than using an aqueous solution (for example, from hours to days instead of days to months). In some embodiments, a "pig" may be used to push the salts out of the conduits. A pig may include any material or device which will fit within the confines of the conduit in conduit heaters such that the pig will move through the conduit while allowing a minimal amount of salt to pass around the pig as it is conveyed through the conduit. Typically a pig is conveyed through a conduit using hydraulic pressure. Using a pig to remove heat transfer fluids may reduce the shut-down time for the circulating molten salt heater to a time period measured in hours. Using a pig to shut-down the heater may include the use of additional specialized surface equipment (for example, modified wellheads, specially designed pigging system for high temperature applications). In certain embodiments, only U-shaped heaters may use a pig during a shut-down procedure. All three shut-down methods have different advantages.

[1390] Fluids may be used to shut-down circulating molten salt heaters. In some embodiments, compressed gases may be used to shut-down circulating molten salt heaters. Compressed gases may combine many of the different advantages of the other three shut-down methods.

[1391] Using compressed gases to shut-down circulating molten salt heaters may have several advantages over using aqueous solutions or secondary fluids. Using compressed gases may be faster, require fewer surfaces resources, more mobile, and allow for emergency shutdown relative to using aqueous solutions or secondary fluids. Using compressed gases to shut-down circulating molten salt heaters has several advantages over using a pig and compressed gases to convey the pig. Using compressed gases may require fewer surfaces resources and have fewer limitations on what types of heaters may be shut down relative to using a pig and compressed gases to convey the pig.

[1392] Some of the disadvantages of using compressed gases include reduced efficiency of salt displacement relative to using aqueous solutions or secondary fluids. In some embodiments, a displacement efficiency of the conveyance of molten salts moving through a conduit heater may be changed by varying the transient pressure profile. Using compressed gases to convey molten salts may result in different types of flow profiles. Varying transient pressure profiles may result

in various pressure profiles including, for example, Taylor flow, dispersed bubble flow, churn flow, or annular flow. Taylor flow may be generally described as a two phase flow pattern such that the gas and molten salt move through the conduit as separate portions (except for a thin film of molten salts along the walls of the conduit between the walls and the portions of gases). Dispersed bubble flow may be generally described as a multiphase flow profile in which the compressed gas moves as small dispersed bubbles through the molten salt. Churn flow may be generally described as a multiphase flow profile (typically observed in near-vertical pipes) in which large, irregular slugs of gas move up the approximate center of the conduit, usually carrying droplets of molten salt with them. Most of the remaining molten salt flows up along the conduit walls. As opposed to Taylor flow, neither phase is continuous and the gas portions are relatively unstable, and take on large, elongated shapes. Churn flow may occur at relatively high gas velocity and as the gas velocity increases, it changes into annular flow. Annular flow may be generally described as a multiphase flow profile in which the compressed gas flows in the approximate center of the conduit, and the molten salt is substantially contained in a thin film on the conduit wall. Annular flow typically occurs at high velocities of the compressed gas, and may be observed in both vertical and horizontal wells.

[1393] Taylor flow may result in maximum displacement efficiency. In some embodiments, modifying the transient pressure profile of compressed gases may allow a maximum displacement efficiency (for example, a Taylor flow profile) to be achieved during shut-down of circulating molten salt heaters. FIGS. 204-208 depict graphical representations on the effect of varying the compressed air mass flow rate (from 1 lb/s (lines 1448) to 2 lb/s (lines 1450) to 10 lb/s (lines 1452)) when using compressed gas to shut-down circulating molten salt heaters. FIG. 204 depicts a graphical representation of the relationship of the salt displacement efficiency over time for three different compressed air mass flow rates. FIG. 205 depicts a graphical representation of the relationship of the air volume flow rate at inlet of a conduit over time for the three different compressed air mass flow rates. FIG. 206 depicts a graphical representation of the relationship of the compressor discharge pressure over time for the three different compressed air mass flow rates. FIG. 207 depicts a graphical representation of the relationship of the salt volume fraction at outlet of a conduit over time for the three different compressed air mass flow rates. FIG. 208 depicts a graphical representation of the relationship of the salt volume flow rate at outlet of a conduit over time for the three different compressed air mass flow rates. FIGS. 204-208 show that higher compressed air mass flow rates are desirable as regards quickly and efficiently shutting down circulating molten salt heaters.

[1394] FIG. 209 depicts a schematic representation of an embodiment of compressed gas shut-down system 1454. In some embodiments, compressed gas shut-down system 1454 may include

storage tanks 1456A-C, heat exchangers 1458, compressors 1460, pumps 1462, and piping 1464A-B. Compressor 1460 may compress gas to be used in shut-down system 1454. Gases may include air, inert gases, byproducts of subsurface treatment processes, or mixtures thereof. Compressed gases are transferred from compressor 1460 to storage tank 1456A. Compressed air may be transferred from storage tank 1456A using piping 1464A to a first end of U-shaped circulating molten salt heaters 412 positioned in formation 492. The compressed air pushes molten salt out of a second end of U-shaped circulating molten salt heaters 412 through piping 1464B to storage tank 1456B. In some embodiments, storage tank 1456B may include a surge vessel which functions to absorb process disturbance and/or momentary unexpected flow changes. The surge vessel may allow compressed air to escape while inhibiting removed salts from escaping. Molten salts may be conveyed from storage tank 1456B through heat exchanger 1458 to storage tank 1456C. Salts in storage tanks 1456C may be conveyed using pumps 1462 to a second set of U-shaped circulating molten salt heaters to heat another formation and/or a second portion of the formation. Compressed gas shut-down system 1454 depicted in FIG. 209 includes two independent systems. The two shut-down systems may be operated independently of each other.

[1395] A portion of the heat input into a treatment area using circulated heat transfer fluid may be recovered after the in situ heat treatment process is completed. Initially, the same heat transfer fluid used to heat the treatment area may be circulated through the formation without the heat source reheating the heat transfer fluid such that the heat transfer fluid absorbs heat from the treatment area. The heat transfer fluid heated by the treatment area may be circulated through an adjacent unheated treatment area to begin heating the unheated treatment area. In some embodiments, the heat transfer fluid heated by the treatment area passes through a heat exchanger to heat a second heat transfer fluid that is used to begin heating the unheated treatment area.

[1396] In some embodiments, a different heat transfer fluid than the heat transfer fluid used to heat the treatment area may be used to recover heat from the formation. A different heat transfer fluid may be used when the heat transfer fluid used to heat the treatment area has the potential to solidify in the piping during recovery of heat from the treatment area. The different heat transfer fluid may be a low melting temperature salt or salt mixture, steam, carbon dioxide, or a synthetic oil (for example, DowTherm or Therminol).

[1397] In some embodiments, initial heating of the formation may be performed using circulated molten solar salt ($NaNO_3$-KNO_3) flowing through conduits in the formation. Heating may be continued until fluid communication between heater wells and producer wells is established and a relatively large amount of coke develops around the heater wells. Circulation may be stopped

and one or more of the conduits may be perforated. In an embodiment, the heater includes a perforated outer conduit and an inner liner that is chemically resistant to the heat transfer fluid. When heat transfer fluid is stopped, the liner may be withdrawn or chemically dissolved to allow fluid flow from the heater into the formation. In other embodiments, perforation guns may be used in the piping after flow of circulated heat transfer fluid is stopped. Nitrate salts or other oxidizers may be introduced into the formation through the perforations. The nitrate salts or other oxidizers may oxidize the coke to finish heating the reservoir to desired temperatures. The concentration and amount of nitrate salts or other oxidizers introduced into the formation may be controlled to control the heating of the formation. Oxidizing the coke in the formation may heat the formation efficiently and reduce the time for heating the formation to a desired temperature. Oxidation product gases may convectively transfer heat in the formation and provide a gas drive that moves formation fluid towards the production wells.

[1398] In some embodiments, a subsurface hydrocarbon containing formation may be treated by the in situ heat treatment process to produce mobilized and/or pyrolyzed products from the formation. A significant amount of carbon in the form of coke and/or residual oil may remain in portions of the formation when production of fluids from the portions is completed. In some embodiments, the coke and/or residual oil in the portions may be utilized to produce heat and/or additional products from the formation.

[1399] In some embodiments, an oxidizing fluid (for example, air, oxygen enriched air, other oxidants) may be introduced into a treatment area that has been treated to react with the coke and/or residual oil in the portion. The temperature of the treatment area may be sufficiently hot to support burning of the coke and/or residual oil without additional energy input from heaters. In some embodiments, additional heat from heaters and/or other heat sources may be used to add additional energy to ensure continued combustion and/or initiate combustion of the coke and/or residual oil. In some embodiments, sufficient oxidizing fluid may be introduced into a wellbore such that the combustion process proceeds continuously. The oxidation of the coke and/or residual oil may significantly heat the treatment area. Some of the heat may transfer to portions of the formation adjacent to the treatment area. The transferred heat may mobilize and/or pyrolyze fluids in the portions of the formation adjacent to the treatment area. The mobilized and/or pyrolyzed fluids may flow to and be produced from production wells near the perimeter of the treatment area.

[1400] Products (for example, gases) produced from the formation heated by combusting coke and/or residual oil in the formation may be at high temperature. In some embodiments, the hot gases may be utilized in an energy recovery cycle (for example, a Kalina cycle or a Rankine cycle) to produce electricity.

[1401] In certain embodiments, thermal energy from the combustion products are collected and used for a variety of applications. Thermal energy may be used to generate electricity as previously mentioned. In some embodiments, however, collected thermal energy is used to heat a second portion of the formation for the purpose of conducting the in situ heat treatment process on the second portion of the formation. In some embodiments, thermal energy is used to heat a second formation substantially adjacent to the first formation.

[1402] In certain embodiment, thermal energy from the combustion products and regions heated by combustion is transferred directly to a heat transfer fluid. The thermal energy collected in this way may be used directly to heat a second portion of the formation for the purpose of conducting the in situ heat treatment process on the second portion of the formation. In some embodiments, thermal energy is used to heat a second formation substantially adjacent to the first formation.

[1403] Recovering energy in the form of thermal energy from the formation (for example, a previously treated formation) may conserve energy and, thus, decrease overall production costs for hydrocarbon production from a particular formation. The energy collected from the combustion of coke and/or residual hydrocarbons may be greater than the energy required to combust the coke/residual hydrocarbons and collect the resulting thermal energy. For example, in a portion of a formation that has undergone in situ upgrading for eight years, energy that results from combustion of the coke/residual hydrocarbons may be about 1.4 times the energy that is required to combust the coke/residual hydrocarbons and collect the energy. Even with as much as 20% energy loss to the overburden during the process compounded with about a 15% efficiency of energy transfer to electricity, one may collect up to 17% of the energy required for treating the formation.

[1404] In certain embodiments, the quantity of energy recovered from the subsurface formation is considerable, as the data in TABLE 7 demonstrates. A formation that has undergone an in situ upgrading process and/or an in situ upgrading process heating cycle for 6 years may yield, upon combustion of the remaining hydrocarbons and coke, a net energy gain of 63% relative to the energy required for the heating cycle. A formation which has undergone an in situ upgrading process and/or an in situ upgrading process heating cycle for 8 years may yield, upon combustion of the remaining hydrocarbons and coke, a net energy gain of 29% relative to the energy required for the heating cycle. The net energy gain is lower for the formation having undergone an 8 year heating cycle for several reasons, as demonstrated in TABLE 7: the heat input required per pattern is greater than for a 6 year heating cycle; and, due to the longer heating cycle, there is considerably less residual hydrocarbons to combust for energy recovery relative to the 6 year heating cycle.

TABLE 7

Duration of heating (years)	6	8
Heat input required/pattern (10^9 BTU)	3.2	3.9
Combustion: coke		
% of heat required	13	18
Combustion: residual hydrocarbons		
% of heat required	358	152
Total (% of heat required, assuming 50% recovery)	186	85
Energy required for air compression (% of heat required, assuming 50% excess air required, at 85% efficiency)	123	56
Net energy gain (% of heat required)	63	29

[1405] In some embodiments, a method for recovering energy from the subsurface hydrocarbon containing formation includes introducing the oxidizing fluid in at least a portion of the formation. The oxidizing fluid may be introduced into at least one wellbore positioned in the portion of the formation. The portion, or treatment area, of the formation may have been previously subjected to the in situ heat treatment process. The treatment area may include elevated levels of coke. In some embodiments, the treatment area is substantially adjacent or surrounding the wellbore.

[1406] The oxidizing fluid may be used to increase the pressure in the wellbore. Increasing the pressure in the wellbore may move the oxidizing fluid through at least a majority of the treatment area. In some embodiments, increasing the pressure in the wellbore moves the oxidizing fluid past the treatment area such that the treatment area is substantially inundated with oxidizing fluid. Inundation with oxidizing fluid may increase the efficiency of the combustion process ensuring that a greater majority of the coke and/or residual oil in the treatment area is consumed during the combustion process. FIG. 210 depicts an end view representation of an embodiment of wellbore 490 in treatment area 730 undergoing a combustion process. In FIG. 210, oxidizing fluid 678 is being conveyed down wellbore 490 and through treatment area 730.

[1407] Upon initiating combustion in the treatment area and pressurizing the wellbore to help ensure the combustion process extends throughout the treatment area, the pressure in the wellbore may be decreased. Decreasing the pressure in the wellbore may draw heated fluids from the treatment area in the wellbore. Heated fluids drawn in the wellbore may be collected. Heated fluids may include heated gases such as unconsumed heated oxidizing fluids and/or heated combustion products. In some embodiments, heated fluids include heated liquid hydrocarbons. FIG. 211 depicts an end view representation of an embodiment of wellbore 490 in treatment area 730 undergoing fluid removal following the combustion process. In FIG. 211,

heated fluids 880 are being drawn out of treatment area 730 through wellbore 490 during a depressurization cycle.

[1408] In some embodiments, the wellbore and/or the treatment area are allowed to rest between pressurization and depressurization cycles for a period of time. Such a "rest period" may increase the efficiency of the combustion process, for example, by allowing injected oxidizing fluids to be more fully consumed before the depressurization and extraction process begins.

[1409] In some embodiments, heated fluids drawn into the wellbore are conveyed to the surface of the formation. The heated fluids may be conveyed to a heat exchanger at the surface of the formation. The heat exchanger may function to collect thermal energy from the heated fluids. The heat exchanger may transfer thermal energy from the heated fluids collected from the formation to one or more heat transfer fluids. In some embodiments, the heat transfer fluid includes thermally conductive gases (for example, helium, steam, carbon dioxide). In certain embodiments, the heat transfer fluid includes molten salts, molten metals, and/or condensable hydrocarbons. Thermal energy collected by the heat transfer fluid may be used in any number of production and/or heating processes. Heated heat transfer fluid may be transferred to a second portion of the formation. The heat transfer fluid may be used to heat the second portion, for example, as part of the in situ conversion process. Heated heat transfer fluid may be transferred to a second formation substantially adjacent to the formation in order to heat a portion of the second formation.

[1410] In some embodiments, the heat transfer fluid is introduced into the wellbore such that heat is transferred from heated fluids in the wellbore to the heat transfer fluid. Thermal energy collected by the heat transfer fluid may be used in any number of production and/or heating processes. FIG. 212 depicts an end view representation of an embodiment of wellbore 490 in a treatment area undergoing a combustion process using circulated heat transfer fluids (for example, a circulated molten salt) to recover energy from the treatment area. In FIG. 212, oxidizing fluids are conveyed into wellbore 490 through first conduits 882. Heated fluids, resulting from the combustion process, are conveyed through second conduits 884. Heat transfer fluids used to recover energy are conveyed through heat transfer fluid conduit 742. In the embodiment depicted in FIG. 212, different conduits are used for injecting/extracting fluids; however, in some embodiments, the same conduit(s) may be used for both injecting and/or extracting fluids. Portions of conduits and/or portions of the wellbore that are positioned in the overburden may be insulated to minimize heat losses in the overburden to increase the efficiency of the energy recovery process.

[1411] Within the treatment area itself, the first and/or second conduits may include multiple openings that act as outlets for oxidizing fluids and/or inlets for heated fluids. The conduits may

be positioned in the wellbore during the initial heat treatment cycle (for example, when heating the formation with molten salt). In some embodiments, before insertion into the formation, the conduits include the multiple openings to be used during the energy recovery cycle after the initial heating cycle. In such embodiments, the conduits may be monitored during the initial heating cycle to ensure the multiple openings remain open and do not get clogged (for example, with coke). In some embodiments, intermittent cycling of a pressurized fluid may be used to keep the openings unclogged.

[1412] In some embodiments, the initial openings in the conduits may be smaller than required for the combustion process; however, after the initial heat treatment cycle, the openings may be enlarged (for example, with a mandrel or other tool) while positioned within the wellbore.

[1413] In some embodiments, the conduits are removed after the initial heating cycle of the formation in order to form the necessary openings in the conduits. The formation may be allowed to cool sufficiently (for example, by circulating water in the formation) such that the conduits may be handled in a safe manner before extracting the conduits.

[1414] Energy recovered from the first portion of the formation may be used for many different processes. One example, as mentioned above, is using the recovered energy to heat the second portion of the formation for various in situ conversion processes. Typically, however, a stable and dependable source of heat for upgrading hydrocarbons in situ is desired. Due to the different pressurization cycles of the coke and/or residual oil combustion process, providing a stable and dependable heat source from the combustion process may be difficult. In some embodiments, the fluctuations in the energy provided from the combustion process may be overcome by linking several wellbores to the surface heat exchanger. The wellbores may be at different phases of the combustion cycle such that over a specified time period the average energy output of the collection of wellbores is substantially stable and consistent relative to the needs of the process using the energy.

[1415] Issues associated with combusting coke in the treatment area using the aforementioned wellbore pressurization cycles may include overheating of the rock and/or wellbore during the combustion process. In certain embodiments, recovering energy from the formation using the combustion of coke enriched treatment areas includes regulating the temperature of the wellbore and/or the treatment area. The temperature of the wellbore and/or the adjoining treatment area may be regulated by adjusting the oxidizing fluid flow rate. Adjusting the flow rate of the oxidizing fluid into the wellbore may assist in controlling the combustion process in the treatment area and, thus, the temperature.

[1416] In some embodiments, the temperature of the wellbore and/or the adjoining treatment area are regulated by adjusting the difference in pressure between the pressurization and

depressurization phases of the cycle. In some embodiments, the temperature of the wellbore and/or the adjoining treatment area are regulated by adjusting the duration of the combustion process itself. In some embodiments, the temperature of the wellbore and/or the adjoining treatment area are regulated by injecting steam in the wellbore to reduce and/or control the temperature.

[1417] In some embodiments, issues with combusting coke in the treatment area using the aforementioned wellbore pressurization cycles include oxidizing fluids injected in the wellbore moving beyond the desired treatment area and into the surrounding formation. Oxidizing fluids moving beyond the treatment area may decrease the efficiency of the combustion within the treatment area. In some embodiments, a barrier is created in the formation. The barrier may be formed around at least a portion of a perimeter of the treatment area. The barrier may function to inhibit oxidizing fluids introduced in the wellbore from being conveyed beyond the treatment area surrounding the wellbore. Creating the barrier around the treatment area may function to increase the efficiency of the combustion process. Increasing the efficiency of the process may reduce the amount of carbon dioxide produced. Barriers may result in the reduction of energy losses due to un-produced fluids.

[1418] In some embodiments, a barrier forming fluid is introduced around the treatment area surrounding the wellbore. The barrier forming fluid may form the barrier around the treatment area under the proper conditions. The barrier forming fluid may block undesirable flow pathways or reduce the permeability of the oxidizing gases under the proper conditions. For example, the barrier forming fluid may function to solidify into a solid barrier under certain conditions. The barrier forming fluid may function to solidify at or below a certain temperature range.

[1419] In some embodiments, the barrier forming fluid includes a slurry. The slurry may be formed from solids mixed with a low volatility solvent. Solids included in the barrier forming fluid may include, but not be limited to, ceramics, micas, and/or clays. Low volatility solvents may include polyglycols, high temperature greases or condensable hydrocarbons, and/or other polymeric materials.

[1420] Barrier forming fluids may include compositions generally referred to as Lost Circulation Materials (LCMs). LCMs are used during drilling of wellbores to seal off existing (natural) fractures and to prevent propagation of drilling-generated fractures that may be formed during the drilling of low pressure zones. When a drill bit encounters an existing fracture or a fracture-susceptible zone in a subsurface hydrocarbon containing formation, drilling may be interrupted due to the loss of drilling fluid. Fractures may result in bleed off and subsequent lost circulation of drilling fluid.

[1421] LCMs may include waste products, which can be obtained relatively inexpensively. Waste products may be obtained from food processing (for example, ground peanut shells, walnut shells, plant fibers, cottonseed hulls) or chemical manufacturing (for example, mica, cellophane, calcium carbonate, ground rubber, polymeric materials) industries. LCMs may be classified based on their properties. For example, there are formation bridging LCMs and seepage loss LCMs. Sometimes, more than one LCM type may be combined and placed down hole, based on the required LCM properties.

[1422] In some embodiments, issues associated with combusting coke in the treatment area using the aforementioned wellbore pressurization cycles include decreased geological stability in the formation upon removal of the coke. As coke is burned and removed during the combustion process, voids may be created in the subsurface formation, especially in the treatment area. The voids created in the formation may lead to instability in the formation. Typically, however, a majority of coke in the formation is concentrated within a relatively small area around wellbores. In some embodiments, after combustion of coke within the treatment area, structural instability is limited to at most about 10 feet, at most about 6 feet, or at most about 3 feet from the wellbore. It is estimated that greater than about 80% of the coke in the area to be treated is typically within 3 feet of the wellbore. If structural instability is limited to such a relatively small area of the formation, then the instability may not cause significant hazards if appropriate precautions are taken. In some embodiments, the extent of any regions of instability due to combustion of coke is controlled by limiting the size of the treatment area using barriers.

[1423] FIG. 213 depicts percentage of the expected coke distribution relative to a distance from a wellbore in an embodiment of in situ heat treatment process of a treatment area in a formation. Two wellbores 490 are represented in FIG. 213 and curves 886-892 are the expected amount of coke volume fraction (ft^3/ft^3) as a function of distance from the wellbore relative to the time period of the initial in situ heat treatment process of the formation. Curve 886 represents a coke distribution expected after 730 days of in situ heat treatment process in the formation. After 730 days there is expected to be about 47% coke, most of which is within about 3 feet of the wellbore. Curve 888 represents a coke distribution expected after 1460 days of in situ heat treatment process in the formation. After 1460 days there is expected to be about 94% coke, most of which is within about 3 feet of the wellbore. Curve 890 represents a coke distribution expected after 2190 days of in situ heat treatment process in the formation. After 2190 days there is expected to be about 99% coke, most of which is within about 10 feet of the wellbore. Curve 892 represents a coke distribution expected after 2920 days of in situ heat treatment process in the formation. After 2920 days there is expected to be about 99% coke, most of which is within about 10 feet-20 of the wellbore. Curves 888-892 demonstrate that the longer the in situ heat

treatment process is continued, the further away from the wellbore the coke begins to accumulate.

[1424] In some embodiments, nuclear energy is used to heat the heat transfer fluid used in a circulation system to heat a portion of the formation. For example, heat supply 708 in FIG. 165 may be a pebble bed reactor or other type of nuclear reactor, such as a light water reactor or a fissile metal hydride reactor. The use of nuclear energy provides a heat source with little or no carbon dioxide emissions. Also, in some embodiments, the use of nuclear energy is more efficient because energy losses resulting from the conversion of heat to electricity and electricity to heat are avoided by directly utilizing the heat produced from the nuclear reactions without producing electricity.

[1425] In some embodiments, a nuclear reactor heats a heat transfer fluid such as helium. For example, helium flows through a pebble bed reactor, and heat transfers to the helium. The helium may be used as the heat transfer fluid to heat the formation. In some embodiments, the nuclear reactor heats helium, and the helium is passed through a heat exchanger to provide heat to another heat transfer fluid used to heat the formation. The nuclear reactor may include a pressure vessel that contains encapsulated enriched uranium dioxide fuel. Helium may be used as a heat transfer fluid to remove heat from the nuclear reactor. Heat may be transferred in a heat exchanger from the helium to the heat transfer fluid used in the circulation system. The heat transfer fluid used in the circulation system may be carbon dioxide, a molten salt, or other fluids. It is of course possible that a heat transfer fluid may not actually be a fluid at certain temperatures. A heat transfer fluid may have many of the properties of a solid at lower temperatures and a fluid at higher temperatures. Pebble bed reactor systems are available, for example, from PBMR Ltd. (Centurion, South Africa).

[1426] FIG. 214 depicts a schematic diagram of a system that uses nuclear energy to heat treatment area 730. The system may include helium system gas mover 894, nuclear reactor 896, heat exchanger unit 898, and heat transfer fluid mover 900. Helium system gas mover 894 may blow, pump, or compress heated helium from nuclear reactor 896 to heat exchanger unit 898. Helium from heat exchanger unit 898 may pass through helium system gas mover 894 to nuclear reactor 896. Helium from nuclear reactor 896 may be at a temperature between about 900 °C and about 1000 °C. Helium from helium gas mover 894 may be at a temperature between about 500 °C and about 600 °C. Heat transfer fluid mover 900 may draw heat transfer fluid from heat exchanger unit 898 through treatment area 730. Heat transfer fluid may pass through heat transfer fluid mover 900 to heat exchanger unit 898. The heat transfer fluid may be carbon dioxide, a molten salt, and/or other fluids. The heat transfer fluid may be at a temperature between about 850 °C and about 950 °C after exiting heat exchanger unit 898.

[1427] In some embodiments, the system includes auxiliary power unit 902. In some embodiments, auxiliary power unit 902 generates power by passing the helium from heat exchanger unit 898 through a generator to make electricity. The helium may be sent to one or more compressors and/or heat exchangers to adjust the pressure and temperature of the helium before the helium is sent to nuclear reactor 896. In some embodiments, auxiliary power unit 902 generates power using a heat transfer fluid (for example, ammonia or aqua ammonia). Helium from heat exchanger unit 898 may be sent to additional heat exchanger units to transfer heat to the heat transfer fluid. The heat transfer fluid may be taken through a power cycle (such as a Kalina cycle) to generate electricity. In an embodiment, nuclear reactor 896 is a 400 MW reactor and auxiliary power unit 902 generates about 30 MW of electricity.

[1428] FIG. 215 depicts a schematic elevational view of an arrangement for an in situ heat treatment process. Wellbores (which may be u-shaped or in other shapes) may be formed in the formation to define treatment areas 730A, 730B, 730C, 730D. Additional treatment areas could be formed to the sides of the shown treatment areas. Treatment areas 730A, 730B, 730C, 730D may have widths of over 300 m, 500 m, 1000 m, or 1500 m. Well exits and entrances for the wellbores may be formed in well openings area 904. Rail lines 906 may be formed along sides of treatment areas 730. Warehouses, administration offices, and/or spent fuel storage facilities may be located near ends of rail lines 906. Facilities 908 may be formed at intervals along spurs of rail lines 906. Facilities 908 may include a nuclear reactor, compressors, heat exchanger units, and/or other equipment needed for circulating hot heat transfer fluid to the wellbores. Facilities 908 may also include surface facilities for treating formation fluid produced from the formation. In some embodiments, heat transfer fluid produced in facility 908' may be reheated by the reactor in facility 908" after passing through treatment area 730A. In some embodiments, each facility 908 is used to provide hot treatment fluid to wells in one half of the treatment area 730 adjacent to the facility. Facilities 908 may be moved by rail to another facility site after production from a treatment area is completed.

[1429] In some embodiments, nuclear energy is used to directly heat a portion of a subsurface formation. The portion of the subsurface formation may be part of a hydrocarbon treatment area. As opposed to using a nuclear reactor facility to heat a heat transfer fluid, which is then provided to the subsurface formation to heat the subsurface formation, one or more self-regulating nuclear heaters may be positioned underground to directly heat the subsurface formation. The self-regulating nuclear reactor may be positioned in or proximate to one or more tunnels.

[1430] In some embodiments, treatment of the subsurface formation requires heating the formation to a desired initial upper range (for example, between about 250 °C and 350 °C). After heating the subsurface formation to the desired temperature range, the temperature may be

maintained in the range for a desired time (for example, until a percentage of hydrocarbons have been pyrolyzed or an average temperature in the formation reaches a selected value). As the formation temperature rises, the heater temperature may be slowly lowered over a period of time. Currently, certain nuclear reactors described herein (for example, nuclear pebble bed reactors), upon activation, reach a natural temperature output limit of about 900 °C, eventually decaying as the uranium-235 fuel is depleted and resulting in lower temperatures produced over time at the heater. The natural power output curve of certain nuclear reactors (for example, nuclear pebble bed reactors) may be used to provide a desired heating versus time profile for certain subsurface formations.

[1431] In some embodiments, nuclear energy is provided by a self-regulating nuclear reactor (for example, a pebble bed reactor or a fissile metal hydride reactor). The self-regulating nuclear reactor may not exceed a certain temperature based upon its design. The self-regulating nuclear reactor may be substantially compact relative to traditional nuclear reactors. The self-regulating nuclear reactor may be, for example, approximately 2 m, 3 m, or 5 m square or even less in size. The self-regulating nuclear reactor may be modular.

[1432] FIG. 216 depicts a schematic representation of self-regulating nuclear reactor 910. In some embodiments, the self-regulating nuclear reactor includes fissile metal hydride 912. The fissile metal hydride may function as both fuel for the nuclear reaction as well as a moderator for the nuclear reaction. A core of the nuclear reactor may include a metal hydride material. The temperature driven mobility of the hydrogen isotope contained in the hydride may function to control the nuclear reaction. If the temperature increases above a set point in core 914 of self-regulating nuclear reactor 910, a hydrogen isotope dissociates from the hydride and escapes out of the core and the power production decreases. If the core temperature decreases, the hydrogen isotope reassociates with the fissile metal hydride reversing the process. In some embodiments, the fissile metal hydride may be in a powdered form, which allows hydrogen to more easily permeate the fissile metal hydride.

[1433] Due to its basic design, the self-regulating nuclear reactor may include few, if any, moving parts associated with the control of the nuclear reaction itself. The small size and simple construction of the self-regulating nuclear reactor may have distinct advantages, especially relative to conventional commercial nuclear reactors used commonly throughout the world today. Advantages may include relative ease of manufacture, transportability, security, safety, and financial feasibility. The compact design of self-regulating nuclear reactors may allow for the reactor to be constructed at one facility and transported to a site of use, such as a hydrocarbon containing formation. Upon arrival and installation, the self-regulating nuclear reactor may be activated.

[1434] Self-regulating nuclear reactors may produce thermal power on the order of tens of megawatts per unit. Two or more self-regulating nuclear reactors may be used at the hydrocarbon containing formation. Self-regulating nuclear reactors may operate at a fuel temperature ranging between about 450 °C and about 900 °C, between about 500 °C and about 800 °C, or between about 550 °C and about 650 °C. The operating temperature may be in the range between about 550 °C and about 600 °C. The operating temperature may be in the range between about 500 °C and about 650 °C.

[1435] Self-regulating nuclear reactors may include energy extraction system 916 in core 914. Energy extraction system 916 may function to extract energy in the form of heat produced by the activated nuclear reactor. The energy extraction system may include a heat transfer fluid that circulates through piping 916A and 916B. At least a portion of the tubing may be positioned in the core of the nuclear reactor. A fluid circulation system may function to continuously circulate heat transfer fluid through the piping. Density and volume of piping positioned in the core may be dependent on the enrichment of the fissile metal hydride.

[1436] In some embodiments, the energy extraction system includes alkali metal (for example, potassium) heat pipes. Heat pipes may further simplify the self-regulating nuclear reactor by eliminating the need for mechanical pumps to convey a heat transfer fluid through the core. Any simplification of the self-regulating nuclear reactor may decrease the chances of any malfunctions and increase the safety of the nuclear reactor. The energy extraction system may include a heat exchanger coupled to the heat pipes. Heat transfer fluids may convey thermal energy from the heat exchanger.

[1437] The dimensions of the nuclear reactor may be determined by the enrichment of the fissile metal hydride. Nuclear reactors with a higher enrichment result in smaller relative reactors. Proper dimensions may be ultimately determined by particular specifications of a hydrocarbon containing formation and the formation's energy needs. In some embodiments, the fissile metal hydride is diluted with a fertile hydride. The fertile hydride may be formed from a different isotope of the fissile portion. The fissile metal hydride may include the fissile hydride U^{235} and the fertile hydride may include the isotope U^{238}. In some embodiments, the core of the nuclear reactor may include a nuclear fuel formed from about 5% of U^{235} and about 95% of U^{238}.

[1438] Other combinations of fissile metal hydrides mixed with fertile or non-fissile hydrides will also work. The fissile metal hydride may include plutonium. Plutonium's low melting temperature (about 640 °C) makes the hydride particles less attractive as a reactor fuel to power a steam generator, but may be useful in other applications requiring lower reactor temperatures. The fissile metal hydride may include thorium hydride. Thorium permits higher temperature operation of the reactor because of its high melting temperature (about 1755 °C). In some

embodiments, different combinations of fissile metal hydrides are used in order to achieve different energy output parameters.

[1439] In some embodiments, nuclear reactor 910 may include one or more hydrogen storage containers 918. A hydrogen storage container may include one or more non-fissile hydrogen absorbing materials to absorb the hydrogen expelled from the core. The non-fissile hydrogen absorbing material may include a non-fissile isotope of the core hydride. The non-fissile hydrogen absorbing material may have a hydride dissociation pressure close to that of the fissile material.

[1440] Core 914 and hydrogen storage containers 918 may be separated by insulation layer 920. The insulation layer may function as a neutron reflector to reduce neutron leakage from the core. The insulation layer may function to reduce thermal feedback. The insulation layer may function to protect the hydrogen storage containers from being heated by the nuclear core (for example, with radiative heating or with convective heating from the gas within the chamber).

[1441] The effective steady-state temperature of the core may be controlled by the ambient hydrogen gas pressure. The ambient hydrogen gas pressure may be controlled by the temperature at which the non-fissile hydrogen absorbing material is maintained. The temperature of the fissile metal hydride may be independent of the amount of energy being extracted. The energy output may be dependent on the ability of the energy extraction system to extract the power from the nuclear reactor.

[1442] Hydrogen gas in the reactor core may be monitored for purity and periodically repressurized to maintain the correct quantity and isotopic content. In some embodiments, the hydrogen gas is maintained via access to the core of the nuclear reactor through one or more pipes (for example, pipes 922A and 922B). The temperature of the self-regulating nuclear reactor may be controlled by controlling a pressure of hydrogen supplied to the self-regulating nuclear reactor. The pressure may be regulated based upon the temperature of the heat transfer fluid at one or more points (for example, at the point where the heat transfer fluid enters one or more wellbores). In some embodiments, the pressure may be regulated, and therefore the thermal energy produced by the self-regulating nuclear reactor, based on one or more conditions associated with the formation being treated. Formation conditions may include, for example, temperature of a portion of the formation, type of formation (for example, coal or tar sands), and/or type of processing method being applied to the formation.

[1443] In some embodiments, the nuclear reaction occurring in the self-regulating nuclear reactor may be controlled by introducing a neutron-absorbing gas. The neutron-absorbing gas may, in sufficient quantities, quench the nuclear reaction in the self-regulating nuclear reactor (ultimately

reducing the temperature of the reactor to ambient temperature). Neutron-absorbing gases may include xenon^{135}.

[1444] In some embodiments, the nuclear reaction of an activated self-regulating nuclear reactor is controlled using control rods. Control rods may be positioned at least partially in at least a portion of the nuclear core of the self-regulating nuclear reactor. Control rods may be formed from one or more neutron-absorbing materials. Neutron-absorbing materials may include, but not be limited to, silver, indium, cadmium, boron, cobalt, hafnium, dysprosium, gadolinium, samarium, erbium, and/or europium.

[1445] Currently, self-regulating nuclear reactors described herein, upon activation, reach a natural temperature output limit of about 900 °C, eventually decaying as the fuel is depleted. The natural power output curve of self-regulating nuclear reactors may be used to provide a desired heating versus time profile for certain subsurface formations.

[1446] In some embodiments, self-regulating nuclear reactors may have a natural energy output which decays at a rate of about 1/E (E is sometimes referred to as Euler's number and is equivalent to about 2.71828). In some embodiments, self-regulating nuclear reactors may have a natural power output that decays to 1/E of the initial power in a period of time of about 4 years to about 8 years. Typically, once a formation has been heated to a desired temperature, less heat is required and the amount of thermal energy put into the formation in order to heat the formation is reduced over time. In some embodiments, heat input to at least a portion of the formation over time approximately correlates to a rate of decay of the power from the self-regulating nuclear reactor. Due to the natural decay of at least some self-regulating nuclear reactors, heating systems may be designed such that the heating systems take advantage of the natural rate of decay of the power from a nuclear reactor. Heating systems typically include two or more heaters. Heaters are typically positioned in wellbores placed throughout the formation. Wellbores may include, for example, u-shaped and L-shaped wellbores or other shapes of wellbores. In some embodiments, spacing between wellbores is determined based on the decay rate of the power output of self-regulating nuclear reactors.

[1447] The self-regulating nuclear reactor may initially provide, to at least a portion of the wellbores, an power output of about 300 watts/foot; and thereafter decreasing over a predetermined time period to about 120 watts/foot. The predetermined time period may be determined by the design of the self-regulating nuclear reactor itself (for example, fuel used in the nuclear core as well as the enrichment of the fuel). The natural decrease in power output may match power injection versus time dependence of the formation. Either variable (for example, power output and/or power injection) may be adjusted so that the two variables at least approximately correlate or match. The self-regulating nuclear reactor may be designed to decay

over a period of 4-9 years, 5-7 years, or about 7 years. The decay period of the self-regulating nuclear reactor may correspond to an IUP (in situ upgrading process) and/or an ICP (in situ conversion process) heating cycle.

[1448] In some embodiments, spacing between heater wellbores depends on a rate of decay of one or more nuclear reactors used to provide power. In some embodiments, spacing between heater wellbores ranges between about 8 meters and about 11 meters, between about 9 meters and about 10 meters, or between about 9.4 meters and about 9.8 meters.

[1449] In certain situations, it may be advantageous to continue a particular level of power output of the self-regulating nuclear reactor for a longer period than the natural decay of the fuel material in the nuclear core would normally allow. In some embodiments, in order to keep the level of output within a desired range, a second self-regulating nuclear reactor may be coupled to the formation being treated (for example, being heated). The second self-regulating nuclear reactor may, in some embodiments, have a decayed power output. The power output of the second reactor may have already decreased due to prior use. The power output of the two self-regulating nuclear reactors may be substantially equivalent to the initial power output of the first self-regulating nuclear reactor and/or a desired power output. Additional self-regulating nuclear reactors may be coupled to the formation as needed to achieve the desired power output. Such a system may advantageously increase the effective useful lifetime of the self-regulating nuclear reactors.

[1450] The effective useful lifetime of self-regulating nuclear reactors may be extended by using the thermal energy produced by the nuclear reactor to produce steam which, depending upon the formation and/or systems used, may require far less thermal energy than other uses outlined herein. Steam may be used for a number of purposes including, but not limited to, producing electricity, producing hydrogen on site, converting hydrocarbons, and/or upgrading hydrocarbons. Hydrocarbons may be converted and/or mobilized in situ by injecting the produced steam in the formation.

[1451] A product stream (for example, a stream including methane, hydrocarbons, and/or heavy hydrocarbons) may be produced from a formation heated with heat transfer fluids that are heated by the nuclear reactor. Steam produced from heat generated by the nuclear reactor or a second nuclear reactor may be used to reform at least a portion of the product stream. The product stream may be reformed to make at least some molecular hydrogen.

[1452] The molecular hydrogen may be used to upgrade at least a portion of the product stream. The molecular hydrogen may be injected in the formation. The product stream may be produced from a surface upgrading process. The product stream may be produced from an in situ heat

treatment process. The product stream may be produced from a subsurface steam heating process.

[1453] At least a portion of the steam may be injected into a subsurface steam heating process. At least some of the steam may be used to reform methane. At least some of the steam may be used for electrical generation. At least a portion of the hydrocarbons in the formation may be mobilized by the steam and/or heat from the steam.

[1454] In some embodiments, self-regulating nuclear reactors may be used to produce electricity (for example, via steam driven turbines). The electricity may be used for any number of applications normally associated with electricity. Specifically, the electricity may be used for applications associated with in situ heat treatment processes requiring energy. Electricity from self-regulating nuclear reactors may be used to provide energy for downhole electric heaters. Electricity may be used to cool fluid for forming a low temperature barrier (frozen barrier) around treatment areas, and/or for providing electricity to treatment facilities located at or near the in situ heat treatment process site. In some embodiments, the electricity produced by the nuclear reactors is used to resistively heat the conduits used to circulate heat transfer fluid through the treatment area. In some embodiments, nuclear power is used to generate electricity that operates compressors and/or pumps (compressors/pumps provide compressed gases (such as oxidizing fluid and/or fuel to a plurality of oxidizer assemblies) to a treatment area) needed for the in situ heat treatment process. A significant cost of the in situ heat treatment process may be operating the compressors and/or pumps over the life of the in situ heat treatment process if conventional electrical energy sources are used to power the compressors and/or pumps of the in situ heat treatment process.

[1455] Converting heat from self-regulating nuclear reactors into electricity may not be the most efficient use of the thermal energy produced by the nuclear reactors. In some embodiments, thermal energy produced by self-regulating nuclear reactors is used to directly heat portions of a formation. In some embodiments, one or more self-regulating nuclear reactors are positioned underground in the formation such that thermal energy produced directly heats at least a portion of the formation. One or more self-regulating nuclear reactors may be positioned underground in the formation below the overburden thus increasing the efficient use of the thermal energy produced by the self-regulating nuclear reactors. Self-regulating nuclear reactors positioned underground may be encased in a material for further protection. For example, self-regulating nuclear reactors positioned underground may be encased in a concrete container.

[1456] In some embodiments, thermal energy produced by self-regulating nuclear reactors may be extracted using heat transfer fluids. Thermal energy produced by self-regulating nuclear reactors may be transferred to and distributed through at least a portion of the formation using

heat transfer fluids. Heat transfer fluids may circulate through the piping of the energy extraction system of the self-regulating nuclear reactor. As heat transfer fluids circulate in and through the core of the self-regulating nuclear reactor, the heat produced from the nuclear reaction heats the heat transfer fluids.

[1457] In some embodiments, two or more heat transfer fluids may be employed to transfer thermal energy produced by self-regulating nuclear reactors. A first heat transfer fluid may circulate through the piping of the energy extraction system of the self-regulating nuclear reactor. The first heat transfer fluid may pass through a heat exchanger and used to heat a second heat transfer fluid. The second heat transfer fluid may be used for treating hydrocarbon fluids in situ, powering electrolysis unit, and/or for other purposes. The first heat transfer fluid and the second heat transfer fluid may be different materials. Using two heat transfer fluids may reduce the risk of unnecessary exposure of systems and personnel to any radiation absorbed by the first heat transfer fluid. Heat transfer fluids that are resistant to absorbing nuclear radiation may be used (for example, nitrite salts or nitrate salts).

[1458] In some embodiments, the energy extraction system includes alkali metal (for example, potassium) heat pipes. Heat pipes may further simplify the self-regulating nuclear reactor by eliminating the need for mechanical pumps to convey a heat transfer fluid through the core. Any simplification of the self-regulating nuclear reactor may decrease the chances of any malfunctions and increase the safety of the nuclear reactor. The energy extraction system may include a heat exchanger coupled to the heat pipes. Heat transfer fluids may convey thermal energy from the heat exchanger.

[1459] Heat transfer fluids may include natural or synthetic oil, molten metal, molten salt, or other types of high temperature heat transfer fluid. The heat transfer fluid may have a low viscosity and a high heat capacity at normal operating conditions. When the heat transfer fluid is a molten salt or other fluid that has the potential to solidify in the formation, piping of the system may be electrically coupled to an electricity source to resistively heat the piping when needed and/or one or more heaters may be positioned in or adjacent to the piping to maintain the heat transfer fluid in a liquid state. In some embodiments, an insulated conductor heater is placed in the piping. The insulated conductor may melt solids in the pipe.

[1460] In some embodiments, heat transfer fluids include molten salts. Molten salts function well as heat transfer fluids due to their typically stable nature as a solid and a liquid, their relatively high heat capacity, and unlike water, their lack of expansion when they solidify. Molten salts have a fairly high melting point and typically a large range over which the salt is liquid before it reaches a temperature high enough to decompose. Due to the wide variety of salts, a salt with a desirable temperature range may be found. If necessary, a mixture of different

salts may be used in order to achieve a molten salt mixture with the appropriate properties (for example, an appropriate temperature range).

[1461] In some embodiments, the molten salt includes a nitrite salt or a combination of nitrite salts. Examples of different nitrite salts may include lithium, sodium, and/or potassium nitrite salts. The molten salt may include about 15 wt. % to about 50 wt. % potassium nitrite salts and about 50 wt. % to about 80 wt. % sodium nitrite salts. The molten salt may include a nitrate salt or a combination of nitrate salts. Examples of different nitrate salts may include lithium, sodium, and/or potassium nitrate salts. The molten salt may include about 15 wt. % to about 60 wt. % potassium nitrate salts and about 40 wt. % to about 80 wt. % sodium nitrate salts. The molten salt may include a mixture of nitrite and nitrate salts. In some embodiments, the molten salt may include HITEC and/or HITEC XL which are available from Coastal Chemical Co., L.L.C. located in Abbeville, Louisiana, U.S.A. HITEC may include a eutectic mixture of sodium nitrite, sodium nitrate, and potassium nitrate. HITEC may include a recommended operating temperature range of between about 149 °C and about 538 °C. HITEC XL may include a eutectic mixture of calcium nitrate, sodium nitrate, and potassium nitrate. In some embodiments, a manufacturing facility may be used to convert nitrite salts to nitrate salts and/or nitrate salts to nitrite salts.

[1462] In some embodiments, the molten salt includes a customized mixture of different salts that achieve a desirable temperature range. A desirable temperature range may be dependent upon the formation and/or material being heated with the molten salt. TABLE 8 depicts ranges of different mixtures of nitrate salts. TABLE 8 demonstrates how varying a ratio of a mixture of different salts may affect the salt's usable temperature range as a heat transfer fluid. For example, a lithium doped nitrate salt mixture (for example, Li:Na:K:NO_3) has several advantages over the non lithium doped nitrate salt mixture (for example, Na:K:NO_3). The Li:Na:K:NO_3 salt mixture may offer a large operating temperature range. The Li:Na:K:NO_3 salt mixture may have a lower melting point, which reduces the preheating requirements.

TABLE 8

NO_3 Salts	**Composition (wt. %)**	**Melting Point (°C)**	**Upper Limit (°C)**
Na:K	60:40	230	565
Li:Na:K	12:18:70	200	550
Li:Na:K	20:28:52	150	550
Li:Na:K	27:33:40	160	550
Li:Na:K	30:18:52	120	550

[1463] In some embodiments, pressurized hot water is used to preheat the piping in heater wellbores such that molten salts may be used. Preheating piping in heater wellbores (for example, to at least approximate the melting point of the molten salt to be used) may inhibit molten salts from freezing and occluding the piping when the molten salt is first circulated through the piping. Piping in the heater wellbore may be preheated using pressurized hot water (for example, water at about 120 °C pressurized to about 15 psi). The piping may be heated until at least a majority of the piping reaches a temperature approximate to the circulating hot water temperature. In some embodiments, the hot water is flushed from the piping with air after the piping has been heated to the desired temperature. A preheated molten salt (for example, $Li:Na:K:NO_3$) may then be circulated through the piping in the heater wellbores to achieve the desired temperature.

[1464] In some embodiments, a salt (for example, $Li:Na:K:NO_3$) is dissolved in water to form a salt solution before circulating the salt through piping in heater wellbores. Dissolving the salt in water may reduce the freezing point (for example, from about 120 °C to about 0 °C) such that the salt may be safely circulated through the piping with little fear of the salt freezing and obstructing the piping. The salt solution, in some embodiments, is preheated (for example, to about 90 °C) before circulating the solution through the piping in heater wellbores. The salt solution may be heated at an elevated pressure (for example, greater than about 15 psi) to above the water's boiling point. As the salt solution is heated to about 120 °C, the water from the solution may evaporate. The evaporating water may be allowed to vent from the heat transfer fluid circulation system. Eventually, only the anhydrous molten salt remains to heat the formation.

[1465] In some embodiments, preheating of piping in heater wellbores is accomplished by a heat trace (for example, an electric heat trace). The heat trace may be accomplished by using a cable and/or running current directly through the pipe. In some embodiments, a relatively thin conductive layer is used to provide the majority of the electrically resistive heat output of the temperature limited heater at temperatures up to a temperature at or near the Curie temperature and/or the phase transformation temperature range of the ferromagnetic conductor. Such a temperature limited heater may be used as the heating member in an insulated conductor heater. The heating member of the insulated conductor heater may be located inside a sheath with an insulation layer between the sheath and the heating member.

[1466] FIG. 217 depicts a schematic representation of an embodiment of an in situ heat treatment system positioned in formation 492 with u-shaped wellbores 924 using self-regulating nuclear reactors 910. Self-regulating nuclear reactors 910, depicted in FIG. 217, may produce about 70 MWthermal. In some embodiments, spacing between wellbores 924 is determined based on the decay rate of the energy output of self-regulating nuclear reactors 910.

[1467] U-shaped wellbores may run down through overburden 400 and into hydrocarbon containing layer 388. The piping in wellbores 924 adjacent to overburden 400 may include insulated portion 926. Insulated storage tanks 928 may receive molten salt from the formation 492 through piping 930. Piping 930 may transport molten salts with temperatures ranging from about 350 °C to about 500 °C. Temperatures in the storage tanks may be dependent on the type of molten salt used. Temperatures in the storage tanks may be in the vicinity of about 350 °C. Pumps may move the molten salt to self-regulating nuclear reactors 910 through piping 932. Each of the pumps may need to move, for example, 6 kg/sec to 12 kg/sec of the molten salt. Each self-regulating nuclear reactor 910 may provide heat to the molten salt. The molten salt may pass from piping 934 to wellbores 924. The heated portion of wellbore 924 that passes through layer 388 may extend, in some embodiments, from about 8,000 feet (about 2400 m) to about 10,000 feet (about 3000 m). Exit temperatures of the molten salt from self-regulating nuclear reactors 910 may be about 550 °C. Each self-regulating nuclear reactor 910 may supply molten salt to about 20 or more wellbores 924 that enter into the formation. The molten salt flows through the formation and back to storage tanks 928 through piping 930.

[1468] In some embodiments, nuclear energy is used in a cogeneration process. In an embodiment for producing hydrocarbons from a hydrocarbon containing formation (for example, a tar sands formation), produced hydrocarbons may include one or more portions with heavy hydrocarbons. Hydrocarbons may be produced from the formation using more than one process. In certain embodiments, nuclear energy is used to assist in producing at least some of the hydrocarbons. At least some of the produced heavy hydrocarbons may be subjected to pyrolysis temperatures. Pyrolysis of the heavy hydrocarbons may be used to produce steam. Steam may be used for a number of purposes including, but not limited to, producing electricity, converting hydrocarbons, and/or upgrading hydrocarbons.

[1469] In some embodiments, a heat transfer fluid is heated using a self-regulating nuclear reactor. The heat transfer fluid may be heated to temperatures that allow for steam production (for example, from about 550 °C to about 600 °C). In some embodiments, in situ heat treatment process gas and/or fuel passes to a reformation unit. In some embodiments, in situ heat treatment process gas is mixed with fuel and then passed to the reformation unit. A portion of in situ heat treatment process gas may enter a gas separation unit. The gas separation unit may remove one or more components from the in situ heat treatment process gas to produce the fuel and one or more other streams (for example, carbon dioxide or hydrogen sulfide). The fuel may include, but not be limited to, hydrogen, hydrocarbons having a carbon number of at most 5, or mixtures thereof.

[1470] The reformer unit may be a steam reformer. The reformer unit may combine steam with a fuel (for example, methane) to produce hydrogen. For example, the reformation unit may include water gas shift catalysts. The reformation unit may include one or more separation systems (for example, membranes and/or a pressure swing adsorption system) capable of separating hydrogen from other components. Reformation of the fuel and/or the in situ heat treatment process gas may produce a hydrogen stream and a carbon oxide stream. Reformation of the fuel and/or the in situ heat treatment process gas may be performed using techniques known in the art for catalytic and/or thermal reformation of hydrocarbons to produce hydrogen. In some embodiments, electrolysis is used to produce hydrogen from the steam. A portion or all of the hydrogen stream may be used for other purposes such as, but not limited to, an energy source and/or a hydrogen source for in situ or ex situ hydrogenation of hydrocarbons.

[1471] Self-regulating nuclear reactors may be used to produce hydrogen at facilities located adjacent to hydrocarbon containing formations. The ability to produce hydrogen on site at hydrocarbon containing formations is highly advantageous due to the plurality of ways in which hydrogen is used for converting and upgrading hydrocarbons on site at hydrocarbon containing formations.

[1472] In some embodiments, the first heat transfer fluid is heated using thermal energy stored in the formation. Thermal energy may result in the formation following a number of different heat treatment methods.

[1473] Self-regulating nuclear reactors have several advantages over many current constant output nuclear reactors. However, there are several new nuclear reactors whose designs have received regulatory approval for construction. Nuclear energy may be provided by a number of different types of available nuclear reactors and nuclear reactors currently under development (for example, generation IV reactors).

[1474] In some embodiments, nuclear reactors include very high temperature reactors (VHTR). VHTRs may use, for example, helium as a coolant to drive a gas turbine for treating hydrocarbon fluids in situ, powering an electrolysis unit, and/or for other purposes. VHTRs may produce heat up to about 950 °C or more. In some embodiments, nuclear reactors include a sodium-cooled fast reactor (SFR). SFRs may be designed on a smaller scale (for example, 50MWe) and therefore may be more cost effective to manufacture on site for treating hydrocarbon fluids in situ, powering electrolysis units, and/or for other purposes. SFRs may be of a modular design and potentially portable. SFRs may produce temperatures ranging between about 500 °C and about 600 °C, between about 525 °C and about 575 °C, or between 540 °C and about 560 °C.

[1475] In some embodiments, pebble bed reactors are employed to provide thermal energy. Pebble bed reactors may produce up to 165 MWe. Pebble bed reactors may produce

temperatures ranging between about 500 °C and about 1100 °C, between about 800 °C and about 1000 °C, or between about 900 °C and about 950 °C. In some embodiments, nuclear reactors include supercritical-water-cooled reactors (SCWR) based at least in part on previous light water reactors (LWR) and supercritical fossil-fired boilers. SCWRs may produce temperatures ranging between about 400 °C and about 650 °C, between about 450 °C and about 550 °C, or between about 500 °C and about 550 °C.

[1476] In some embodiments, nuclear reactors include lead-cooled fast reactors (LFR). LFRs may be manufactured in a range of sizes, from modular systems to several hundred megawatt or more. LFRs may produce temperatures ranging between about 400 °C and about 900 °C, between about 500 °C and about 850 °C, or between about 550 °C and about 800 °C.

[1477] In some embodiments, nuclear reactors include molten salt reactors (MSR). MSRs may include fissile, fertile, and fission isotopes dissolved in a molten fluoride salt with a boiling point of about 1,400 °C. The molten fluoride salt may function as both the reactor fuel and the coolant. MSRs may produce temperatures ranging between about 400 °C and about 900 °C, between about 500 °C and about 850 °C, or between about 600 °C and about 800 °C.

[1478] In some in situ heat treatment embodiments, compressors provide compressed gases to the treatment area. For example, compressors may be used to provide oxidizing fluid 678 and/or fuel 936 to a plurality of oxidizer assemblies. Oxidizers may burn a mixture of oxidizing fluid 678 and fuel 936 to produce heat that heats the treatment area in the formation. Also, compressors 714 may be used to supply gas phase heat transfer fluid to the formation as depicted in FIG. 165. In some embodiments, pumps provide liquid phase heat transfer fluid to the treatment area.

[1479] A significant cost of the in situ heat treatment process may be operating the compressors and/or pumps over the life of the in situ heat treatment process if conventional electrical energy sources are used to power the compressors and/or pumps of the in situ heat treatment process. In some embodiments, nuclear power may be used to generate electricity that operates the compressors and/or pumps needed for the in situ heat treatment process. The nuclear power may be supplied by one or more nuclear reactors. The nuclear reactors may be light water reactors, pebble bed reactors, and/or other types of nuclear reactors. The nuclear reactors may be located at or near to the in situ heat treatment process site. Locating the nuclear reactors at or near to the in situ heat treatment process site may reduce equipment costs and electrical transmission losses over long distances. The use of nuclear power may reduce or eliminate the amount of carbon dioxide generation associated with operating the compressors and/or pumps over the life of the in situ heat treatment process.

[1480] Excess electricity generated by the nuclear reactors may be used for other in situ heat treatment process needs. For example, excess electricity may be used to cool fluid for forming a low temperature barrier (frozen barrier) around treatment areas, and/or for providing electricity to treatment facilities located at or near the in situ heat treatment process site. In some embodiments, the electricity or excess electricity produced by the nuclear reactors may be used to resistively heat the conduits used to circulate heat transfer fluid through the treatment area.

[1481] In some embodiments, excess heat available from the nuclear reactors may be used for other in situ processes. For example, excess heat may be used to heat water or make steam that is used in solution mining processes. In some embodiments, excess heat from the nuclear reactors may be used to heat fluids used in the treatment facilities located near or at the in situ heat treatment site.

[1482] In some embodiments, the molten salt includes a carbonate salt or a mixture of carbonate salts. Examples of different carbonate salts may include lithium, sodium, and/or potassium carbonate salts. The molten salt may include about 40% to about 60% by weight lithium carbonate, from about 20% to about 40% by weight sodium carbonate salt and about 20% to about 30% by weight potassium carbonate. In some embodiments, the molten salt is a eutectic mixture of carbonate salts. The eutectic carbonate salt mixture may be a mixture of carbonate salts having a melting point above 390 °C, or from about 390 °C to about 700 °C, or about 600 °C. The composition of the carbonate molten salt may be varied to produce a carbonate molten salt having a desired melting point using for example, known phase diagrams for eutectic carbonate salts. For example, a carbonate molten salt containing 44% by weight lithium carbonate, 31% by weight sodium carbonate, and 25% by weight potassium carbonate has a melting point of about 395 °C. Due to higher melting points, heat transfer from hot carbonate molten salts to the formation may be enhanced. Higher temperature may reduce the time necessary to heat the formation to a desired temperature.

[1483] In some in situ heat treatment process embodiments, a circulation system containing carbonate molten salts is used to heat the formation. Using the carbonate molten salt circulation system for in situ heat treatment of a hydrocarbon containing formation may reduce energy costs for treating the formation, reduce the need for leakage surveillance, and/or facilitate heating system installation.

[1484] In some embodiments, a carbonate molten salt is used to heat the formation. In some embodiments, a carbonate molten salt is provided to piping in a formation after the formation has been heated using a heat transfer fluid described herein. The use of a carbonate molten salt may allow the formation to be heated if piping in the formation develops leakage. In some embodiments, disposable piping may be used in the formation. In some embodiments, carbonate

molten salts are used in circulation systems that have been abandoned. For example, a carbonate molten salt may be circulated in piping in a formation that has developed leaks.

[1485] FIG. 218, depicts a schematic representation of a system for heating a formation using carbonate molten salt. FIG. 219 depicts a schematic representation of an embodiment of a section of the formation after heating the formation with a carbonate molten salt over a period of time. FIG. 220 depicts a cross-sectional representation of an embodiment of a section of the formation after heating the formation with a carbonate molten salt. Piping may be positioned in the u-shaped wellbore to form u-shaped heater 412. Heater 412 is positioned in wellbores 490 and connected to heat transfer fluid circulation system 706 by piping. Wellbore 490 may be an open wellbore. In some embodiments, the vertical or overburden portions 1466 of wellbore 490 are cemented with non-conductive cement or foam cement. Portions 1468 of heater 412 in the overburden may be made of material chemically resistant to hot carbonate salts (for example, stainless steel tubing). Portion 1472 of heater 412 may be manufactured from materials that degrade over time. For example, carbon steel, or alloys having a low chromium content. Carbonate molten salt 1470 may enter one end of heater 412 and exit another end of the heater. Flow of hot carbonate molten salt 1470 provides heat to at least a portion of hydrocarbon layer 388.

[1486] Over time contact of carbonate molten salt 1470 may degrade or decompose parts of portion 1472 of heater 412 to form openings in the portion (as shown in FIG. 219). In some embodiments, portion 1472 may include perforations that may be opened or have coverings made of material that degrades over time that allows carbonate molten salt 1470 to flow into hydrocarbon layer 388. As hot carbonate molten salt contacts cooler portions of hydrocarbon layer 388, the hot carbonate molten salt may cool and solidify. Formation of openings in portion 1472 may allow carbonate molten salt 1470 to flow into a second portion of hydrocarbon layer 388. As carbonate molten salt 1470 enters a cooler section of the formation, the carbonate molten salt may become solid or partially solidify. The solidified carbonate molten salt may liquefy or melt when contacted with new hot molten carbonate salt flowing through heater 412. Melting of the solid molten carbonate salt may move more carbonate molten salt into hydrocarbon layer 388. The cycle of solidification and melting of the carbonate molten salt may create permeable heater 1476 that surrounds portion 1472 of heater 412, (as shown in FIG. 220). Permeable heater 1476 may have a diameter at least about 1 diameter or about 2 diameters greater than portion 1472 of heater 412. Formation of permeable heater 1476 in situ may allow the carbonate molten salt flow through the permeable heater and heat additional portions of hydrocarbon layer 388. The ability to heat additional portion of hydrocarbon layer 388 with a

permeable heater may reduce the amount of heaters required and/or time necessary to heat the formation.

[1487] In some embodiments, permeability or injectivity in a hydrocarbon containing formation is created by selectively fracturing portions of the formation. A solid salt composition may be injected into a section of the formation (for example, a lithium/sodium/potassium nitrate salts and/or lithium/sodium/potassium carbonate salts). In some embodiments, the solid salt composition is moved through the formation using a gas, for example, carbon dioxide, or hydrocarbon gas. In some embodiments, the solid salt composition may be provided to the formation as an aqueous slurry. Heat may be provided from one or more heaters to heat the portion to about a melting point of the salt. The heaters may be temperature limited heaters. As the solid salt composition becomes molten or liquid, the pressure in the formation may increase from expansion of the melting solid salt composition. The expansion pressure may be at a pressure effective to fracture the formation, but below the fracture pressure of the overburden. Fracturing of the section may increase permeability of the formation. In some embodiments, at least a portion of the heated solid salt compositions contacts at least some hydrocarbons causes an increase in pressure in the section and create fractures in the formation.

[1488] The molten salt may move through the formation towards cooler portions of the formation and solidify. In some embodiments, heaters may be positioned in some of the fractures in the section and heat is provided to a second section of the formation. In some embodiments, heat from the heaters in the fractures may melt or liquefy the solid salt composition and more fractures may be formed in the formation. In some embodiments, the heaters melt the molten salt and heat from the molten salt is transferred to the formation. In some embodiments, fluid is injected into at least some of fractures formed in the section. Use of molten salts to increase permeability in formations may allow heating of relatively shallow formations with low overburden fracture pressures.

[1489] Fractures may be created by expansion of the heated portion of the formation matrix. Heating in shallow portions of a formation (for example, at a depth ranging from 150 m to 400 m) may cause expansion of the formation and create fractures in the overburden. Expansion in a formation may occur rapidly when the formation is heated at temperatures below pyrolysis temperatures. For example, the formation may be heated to an average temperature of up to about 200 °C. Expansion in the formation is generally much slower when the formation is heated at average temperatures ranging from about 200 °C to about 350 °C. At temperatures above pyrolysis temperatures (for example, temperatures ranging from 230 °C to 900 °C, from 240 °C to 400 °C or from 250 °C to 350 °C), there may be little or no expansion in the formation. In some formations, there may be compaction of the formation above pyrolysis temperatures.

[1490] In some embodiments, a formation includes an upper layer and lower layer with similar formation matrixes that have different initial porosities. For example, the lower layer may have sufficient initial porosity such that the thermal expansion of the upper layer is minimal or substantially none whereas the upper layer may not have sufficient initial porosity so the upper layer expands when heated.

[1491] In some embodiments, a hydrocarbon formation is heated in stages using an in situ heat treatment process to allow production of formation fluids from a shallow portion of the formation. Heating layers of a hydrocarbon formation in stages may control thermal expansion of the formation and inhibit overburden fracturing. Heating an upper layer of the formation after significant pyrolysis of a lower layer of the formation occurs may reduce, inhibit, and/or accommodate the effects of pressure in the formation, thus inhibiting fracturing of the overburden. Staged heating of layers of a hydrocarbon formation may allow production of hydrocarbons from shallow portions of the formation that otherwise could not be produced due to fracturing of the overburden.

[1492] FIGS. 221A and 221B depict representations of an embodiment of heating a hydrocarbon containing formation in stages. Heating lower layer 388A prior to heating upper layer 388B may reduce and/or control the effects of thermal expansion in the formation during a selected period of time. FIG. 221A depicts hydrocarbon layer having lower layer 388A and upper layer 388B. Lower layer 388A may be heated a selected period of time to create permeability and/or porosity in the lower layer to allow thermal expansion of upper layer 388B into lower layer 388A. In some embodiments, a lower layer of the formation is heated above a pyrolyzation temperature. In some embodiments, a lower layer of the formation is heated an average temperature during in situ heat treatment of the formation ranging from at least 230 °C or from about 230 °C to about 370 °C. During the selected period of time, some (and some cases significant amount of) thermal expansion may take place in lower layer 388A.

[1493] Heating of lower layer 388A prior to heating upper layer 388B may control expansion of the upper layer and inhibit fracturing of overburden 400. Heating of the lower layer 388A at temperatures greater than pyrolyzation temperatures may create sufficient permeability and/or porosity in lower layer 388A that upon heating upper layer 388B fluids and/or materials in the upper layer may thermally expand and flow into the lower layer. Sufficient permeability and/or porosity in lower layer 388A may be created to allow pressure generated during heating of upper layer 388B to be released into the lower layer and not the overburden, and thus, fracturing of the overburden may be prevented/inhibited.

[1494] The depth of lower layer 388A and upper layer 388B in the formation may be selected to maximize expansion of the upper layer into the lower layer. For example, a depth of lower layer

388A may be at least from about 400 m to about 750 m from the surface of the formation. A depth of upper layer 388B may be 150 m to about 400 m from the surface of the formation. In some embodiments, lower layer 388A of the formation may have different thermal conductivities and/or different thermal expansion coefficients than layer 388B. Fluid from lower layer 388A may be produced from the lower layer using production wells 206. Hydrocarbons produced from lower layer 388A prior to heating upper layer 388B may include mobilized and/or pyrolyzed hydrocarbons.

[1495] The depth of layers in the formation may be determined by simulation, calculation, or any suitable method for estimating the extent of expansion that will occur in a layer when the layer is heated to a selected average temperature. The amount of expansion caused by heating of the formation may be estimated based on factors such as, but not limited to, measured or estimated richness of layers in the formation, thermal conductivity of layers in the formation, thermal expansion coefficients (for example, a linear thermal expansion coefficient) of layers in the formation, formation stresses, and expected temperature of layers in the formation. Simulations may also take into effect strength characteristics of a rock matrix.

[1496] In certain embodiments, heaters 412 in lower layer 388A may be turned on for a selected period of time. Heaters 412 in lower layer 388A and upper layer 388B may be vertical or horizontal heaters. After heating lower layer 388A for a period of time, heaters 412 in upper layer 388B may be turned on. In some embodiments, heaters 412 in lower layer 388A are vertical heaters that are raised to upper layer 388B after the lower layer is heated for a selected period of time. Any pattern or number of heaters may be used to heat the layers.

[1497] Heaters 412 in upper layer 388B may be turned on at, or near, the completion of heating of lower layer 388A. For example, heaters 412 in upper layer 388B may be turned on, or begin heating, within about 9 months, about 24 months, or about 36 months from the time heaters 412 in lower layer 388A begin heating. Heaters 412 in upper layer 388B may be turned on after a selected amount of pyrolyzation, and/or hydrocarbon production has occurred in lower layer 388A. In one embodiment, heaters 412 in upper layer 388B are turned on after sufficient permeability in lower layer 388A is created and/or pyrolyzation of lower layer 388A has been completed. Treatment of lower layer 388A may sufficient when the layer lower layer is sufficiently compacted as determined using optic fiber techniques (for example, real-time compaction imaging) or radioactive bullets, when average temperature of the formation is at least 230 °C, or greater than 260 °C, and/or when production of at least 10%, at least 20%, or at least 30% of the expected volume of hydrocarbons has occurred.

[1498] Upper layer 388B may be heated by heaters 412 at a rate sufficient to allow expansion of the upper layer into lower layer 388A and thus inhibit fracturing of the overburden. Portion **1418**

of upper layer 388B may sag into lower layer 388A as shown in 221B. Upon heating, sagged portion **1418** of upper layer 388B may expand back to the surface (for example, return to the flat shape depicted in FIG. 221A). Allowing the upper layer to sag into the lower layer and expand back to the surface may inhibit or lower tensile stress in the overburden that may result in surface fissures. Heaters 412 may heat upper layer 388B to an average temperature from about 200 °C to about 370 °C for a selected amount of time.

[1499] After and/or during of treatment of upper layer 388B, fluids from the upper and lower layer may be produced from the lower layer using production well 206. Hydrocarbons produced from production well 206 may include pyrolyzed hydrocarbons from the upper layer. In some embodiments, fluids are produced from upper layer 388B.

[1500] In some embodiments, a hydrocarbon containing formation is treated using an in situ heat treatment process to remove methane from the formation. The hydrocarbon containing formation may be an oil shale formation and/or contain coal. In some embodiments, a barrier is formed around the portion to be heated. In some embodiments, the hydrocarbon containing formation includes a coal containing layer (a deep coal seam) underneath a layer of oil shale. The coal containing layer may contain significantly more methane than the oil shale layer. For example, the coal containing layer may have a volume of methane that is five times greater than a volume of methane in the oil shale layer. Wellbores may be formed that extend through the oil shale layer into the coal containing layer.

[1501] Heat may be provided to the hydrocarbon containing formation from a plurality of heaters located in the formation. One or more of the heaters may be temperature limited heaters and or one or more insulated conductors (for example, a mineral insulated conductor). The heating may be controlled to allow treatment of the oil shale layer while maintaining a temperature of the coal containing layer below a pyrolysis temperature.

[1502] After treatment of the oil shale layer, heaters may be extended into the coal containing layer. The temperature in the coal containing layer may be maintained below a pyrolysis temperature of hydrocarbons in the formation. In some embodiments, the coal containing layer is maintained at a temperature from about 30 °C to 40 °C. As the temperature of the coal containing layer increases, methane may be released from the formation. The methane may be produced from the coal containing layer. In some embodiments, hydrocarbons having a carbon number between 1 and 5 are released from the coal continuing layer of the formation and produced from the formation.

[1503] In some embodiments, amounts of ammonia and/or hydrogen sulfide produced from a hydrocarbon containing formation hydrogen may vary depending on the geology of the hydrocarbon containing formation. During an in situ heat treatment process, hydrocarbon

containing formation that have a high content of sulfur and/or nitrogen may produce a significant amount of ammonia and/or hydrogen sulfide and/or formation fluids that include a significant amount of ammonia and/or hydrogen sulfide. During heating, at least a portion of the ammonia may be oxidized to NOx compounds. The formation fluid may have to be treated to remove the ammonia, NOx and/or hydrogen sulfide prior to processing in a surface facility and/or transporting the formation fluid. Treatment of the formation fluid may include, but is not limited to, gas separation methods, adsorption methods or any known method to remove hydrogen sulfide, ammonia and/or NOx from the formation fluid. In some embodiments, the hydrocarbon formation includes a significant amount of compounds that off-gas ammonia and/or hydrogen sulfide that the formation is deemed unacceptable for treatment.

[1504] The nitrogen content in the hydrocarbon containing formation may come from hydrocarbon compounds that contain nitrogen, inorganic compounds and/or ammonium feldspars (for example, buddingtonite ($NH_4AlSi_3O_8$)).

[1505] The sulfur content in the hydrocarbon containing formation may come from organic sulfur and/or inorganic compounds. Inorganic compounds include, but are not limited to, sulfates, pyrites, metal sulfides, and mixtures thereof. Treatment of formations containing significant amounts of total sulfur may result in release of unpredictable amounts of hydrogen sulfide. As shown in TABLE 9, formations having different amounts of total sulfur produce varying amounts of hydrogen sulfide, especially when the formations contain a significant amount of organosulfur compounds and/or sulfate compounds. For example comparing same 3 with sample 4 TABLE 9, the different amounts of hydrogen sulfide produced does not directly correlate to the total sulfur present in the sulfur.

TABLE 9

Sample No.	Total Sulfur, %wt.	H2S yield, %wt
1	0.68	0.08
2	0.93	0.17
3	0.99	0.32
4	1.09	0.06
5	1.11	0.19
6	1.11	0.17
7	1.16	0.15
8	1.24	0.17
9	1.35	0.34
10	1.37.	0.31

Sample No.	Total Sulfur, %wt.	H2S yield, %wt
11	1.45	0.63
12	1.53	0.54
13	1.55	0.27
14	2.61	0.39

[1506] Treatment to remove unwanted gases produced during production of hydrocarbons from a formation may be expensive and/or inefficient. Many methods have been developed to reduce the amount of ammonia and/or hydrogen sulfide by adding solutions to hydrocarbon containing formations that neutralize or complex the nitrogen and/or sulfur in the formation. Methods to produce formation fluids having reduced amounts of undesired gases (for example, hydrogen sulfide, ammonia and/or NOx compounds are desired).

[1507] It has been found that the amount of hydrogen sulfide produced from a hydrocarbon containing formation correlates with the amount of pyritic sulfur in the formation. TABLE 10 is a tabulation of percent by weight pyritic sulfur in layers of a hydrocarbon containing formation that include pyritic sulfur and the percent by weight hydrogen sulfide produced from the layer upon heating. As shown in TABLE 10, the amount of hydrogen sulfide produced increases with the amount of pyritic sulfur in the layer.

TABLE 10

Hydrocarbon Layer No.	Pyritic Sulfur, %wt	H2S %wt
1	0.73	0.32
2	0.68	0.06
3	1.23	0.54
4	1.01	0.34
5	2.08	0.39
6	0.95	0.63
7	0.66	0.19
8	0.55	0.15
9	0.50	0.17
10	0.95	0.27
11	0.50	0.17
12	0.92	0.31
13	0.23	0.08

Hydrocarbon Layer No.	Pyritic Sulfur, %wt	H2S %wt
14	0.54	0.17

[1508] In some embodiments, a hydrocarbon formation is assessed using known methods (for example, Fischer Assay data and/or 34S isotope data) to determine the total amount of inorganic sulfur compounds and/or total amount of inorganic nitrogen compounds in the formation. Based on the assessed amount of ammonia and/or metal sulfide (for example, pyrite) in a portion of the formation, heaters may be positioned in portions of the formation to selectively heat the formation while inhibiting the amount of hydrogen sulfide and/or ammonia produced during treatment. Such selective heating allows treatment of formations containing significant amounts of ammonia, pyrite and/or metal sulfides for production of hydrocarbons.

[1509] In some embodiments, heat is provided to a first portion of a hydrocarbon containing formation from one or more heaters and/or heat sources. In some embodiments, at least a portion of the heaters in the first section are substantially horizontal. Heat from heaters in the first section raise a temperature of the first section to above a mobilization temperature. During heating, a portion of the hydrocarbons in the first section may be mobilized. Hydrocarbons may be produced from the first section. In some embodiments, hydrocarbons in the first section are heated to a pyrolysis temperature and at least a portion of the hydrocarbons are pyrolyzed to form hydrocarbon gases.

[1510] A second section in the formation may include a significant amount of inorganic sulfur compounds and/or inorganic nitrogen compounds. In some embodiments, the second section may contain at least 0.1% by weight, at least 0.5% by weight, or at least 1% by weight pyrite. The second section may provide structural strength to the formation. Maintaining a second section below the pyrolysis and/or mobilization temperature of hydrocarbons may inhibit production of undesirable gases (for example, hydrogen sulfide and/or ammonia) from the second section. In some embodiments, the formation includes alternating layers of hydrocarbons, inorganic metal sulfides, and ammonia compounds having different concentrations. In some in situ conversion embodiments, columns of untreated portions of formation may remain in a formation that has undergone in situ heat treatment process.

[1511] A second section of the formation adjacent to the first section may remain untreated by controlling an average temperature in the second portion below a pyrolysis and/or a mobilization temperature of hydrocarbons in the second section. In some embodiments, the average temperature of the second section may be less than 230 °C or from about 25°C to 300 °C. In some embodiments, the average temperature of the second section is below the decomposition of the inorganic sulfur compounds (for example, pyrite). For example, the temperature in the

second section may be less than 300 °C, less than about 230 °C, or from about 25°C to up to the decomposition temperature of the inorganic sulfur compound.

[1512] In some embodiments, an average temperature in the second section is maintained by positioning barrier wells between the first section and the second section and/or the second section and/or the third section of the formation.

[1513] In some embodiments, the untreated second section may be between the first section and a third section of the formation. Heat may be provided to the third portion of the hydrocarbon containing formation. Heaters in the first section and third section may be substantially horizontal. Formation fluids may be produced from the third section of the formation. A processed formation may have a pattern with alternating treated portions and untreated portions. In some embodiments, the untreated second portion may be adjacent to the first section of the formation that is subjected to pyrolysis.

[1514] In some embodiments, at least a portion of the heaters in the first section are substantially vertical and may extend into or through one or more sections of the formation (for example, through a first vertical section, a second vertical section and/or a third vertical section). The average temperature in the second section may be controlled by selectively controlling the heat produced from the portion of the heater in the second section. Heat from the second section of the heater may be controlled by blocking, turning down, and/or turning off the second portion of the heater so that a minimal amount of heat or no heat is provided to the second section.

[1515] In some embodiments, formation fluid from the first section may be mobilized through the second section. The formation fluid may include gaseous hydrocarbons and/or mercury. The formation fluid may contact inorganic sulfur compounds (for example, pyrite) in the second section. Contact of the formation fluid with the inorganic sulfur compounds may remove at least a portion of the mercury from the formation fluid. Contact of the inorganic sulfur compounds may produce one or more mercury sulfides that precipitate from the formation fluid and remain in the second section.

[1516] In some embodiments, one or more portions of formation enriched in pyrite (FeS_2) are heated to a temperature under formation conditions such that at least a portion of the pyrite compounds are converted to troilite (FeS) and/or one or more pyrrhotite compounds (FeS_x, $1.0< x< 1.23$) and gaseous sulfur. For example, the second section may be heated temperatures ranging from about 250 °C to about 750 °C, from about 300 °C to about 600 °C, or from about 400 °C to about 500 °C. Troilite and/or pyrrhotite compounds may react with mercury entrained in gaseous hydrocarbons to form mercury sulfide more rapidly than pyrite under formation conditions (for example, under a hydrogen atmosphere and/or at a pH of less than 7).

[1517] The second section may be sufficient permeability to allow gaseous hydrocarbons to flow through the section. In some embodiments, the second section contains less hydrocarbons (hydrocarbon lean) than the first section (hydrocarbon rich). After heating the second section for a period of time to convert some of the pyrite to pyrrhotite, the hydrocarbon rich first section may be heated using an in situ heat treatment process. In some embodiments, hydrocarbons are mobilized and produced from the second section. Formation fluid containing mercury from the first section may be mobilized through the second section of the formation containing pyrrhotite to a third section.

[1518] Contact of the mobilized formation fluid with the pyrrhotite may remove some or all of the mercury from the formation fluid. The contacted formation fluid may be produced from the formation. In some embodiments, the contacted formation fluid is produced from a heated third section of the formation. The contacted formation fluid may be substantially free of mercury or contain a minimal amount of mercury. In some embodiments, the contacted formation fluid has a mercury amount in the contacted formation is less than 10 ppb by weight.

[1519] FIGS. 222 through 224 depict representations of embodiments of treating hydrocarbon formations containing inorganic sulfur and/or inorganic nitrogen compounds. FIG. 222 is a representation of an embodiment of treating hydrocarbon formations containing sulfur and/or inorganic nitrogen compounds. FIG. 223 depicts a representation of an embodiment of treating hydrocarbon formations containing inorganic compounds using selected heating. FIG. 224 depicts a representation of an embodiment of treating hydrocarbon formation using an in situ heat treatment process with subsurface removal of mercury from formation fluid.

[1520] Heat from heaters 412 may heat portions of first section 1420 and/or third section 1422 of hydrocarbon layer 388. Hydrocarbon layer may be below overburden 400. As shown in FIG. 222, heaters in the first section and third section may be substantially horizontal. Heaters 412 may go in and out of the page. Untreated second section 1424 is between first section 1420 and third section 1422. Although shown in a horizontal configuration, it should be understood that second section 1424 may be, in some embodiments, substantially above first section 1420 and substantially below third section 1422 in the formation. Untreated second section 1424 may include inorganic sulfur and/or inorganic nitrogen compounds. For example second section 1424 may include pyrite. Heat from heaters 412 may pyrolyze and/or mobilize a portion of hydrocarbons in first section 1420 and/or third section 1422. Hydrocarbons may be produced through productions wells 206 in first section 1420 and/or third section 1422.

[1521] As shown in FIG. 223, heater 412 is substantially vertical and extends through sections 1420, 1424. Heat from portions 412A of heater 412 may provide heat to first section 1420 of hydrocarbon layer 388. Portion 412B of heater 412A may be inhibited from providing heat

below a mobilization and/or a pyrolyzation temperature to second section 1424. Hydrocarbons may be mobilized in first section 1420 and produced from the formation using production well 206.

[1522] In some embodiments, hydrocarbons in first section 1420 may include mercury and/or mercury compounds and second section 1424 contains troilite and/or pyrite. Heat from heaters 412 may heat portions of first section 1420 and/or third section 1422 (shown in FIG. 222) of hydrocarbon layer 388.

[1523] Hydrocarbons may be pyrolyzed and/or mobilized in first section 1420. As shown in FIG. 222, hydrocarbons may move from first section 1420 through untreated second section 1424 towards third section 1422 as shown by arrows 1426. Pressure in heater wells may be adjusted to push gaseous hydrocarbons into second section 1424. In some embodiments, a drive fluid, for example, carbon dioxide is used to drive the gaseous hydrocarbons towards second section 1424. In certain embodiments, gaseous hydrocarbons are produced from the third section 1422 and liquid hydrocarbons are produced from first section 1420.

[1524] As shown in FIG. 224, heat from heaters 412 heats second section 1424 to convert some of the inorganic sulfur in the second section to a form of inorganic sulfur reactive to mercury (for example, pyrite is converted to troilite). After heating second section 1424, heat from heaters 412 may heat first section 1420 and heat hydrocarbons to a mobilization temperature. Hydrocarbons gases may move from first section 1420 through heated second section 1424 and be produced from production wells 206 in the second section as shown by arrows 1426. Pressure in heater wells may be adjusted to push hydrocarbons into second section 1424. During production of hydrocarbons from first section 1420, casing vents of the production wells 206 of the first section may be closed with production pumps running so that liquid hydrocarbons are produced through the tubing of the production wells. Thus, preventing any entrainment of liquid hydrocarbons in second section 1424.

[1525] As the hydrocarbons flow through second section 1424, contact of hydrocarbons with inorganic sulfur (for example, pyrite and/or troilite) in the second section may complex and/or react with mercury and/or mercury compounds. Contact of mercury and/or mercury compounds with pyrite may remove the mercury and/or mercury compounds from the hydrocarbons. In some embodiments, insoluble mercury sulfides are formed that precipitate from the hydrocarbons. Mercury free hydrocarbons may be produced through productions wells 206 in second sections 1424 (as shown in FIG. 224 and/or third section 1422 (as shown in FIG. 222)).

[1526] In certain embodiments, a solvation fluid and/or pressurizing fluid are used to treat the hydrocarbon formation in addition to the in situ heat treatment process. In some embodiments, a

solvation fluid and/or pressurizing fluid is used after the hydrocarbon formation has been treated using a drive process.

[1527] In some embodiments, heaters are used to heat a first section the formation. For example, heaters may be used to heat a first section of formation to pyrolysis temperatures to produce formation fluids. In some embodiments, heaters are used to heat a first section of the formation to temperatures below pyrolysis temperatures to visbreak and/or mobilize fluids in the formation. In other embodiments, a first section of a formation is heated by heaters prior to, during, or after a drive process is used to produce formation fluids.

[1528] Residual heat from first section may transfer to portions of the formation above, below, and/or adjacent to the first section. The transferred residual heat, however, may not be sufficient to mobilize the fluids in the other portions of the formation towards production wells so that recovery of the fluids from the colder sections fluids may be difficult. Addition of a fluid (for example, a solvation fluid and/or a pressurizing fluid) may solubilize and/or drive the hydrocarbons in the sections of the formation heated by residual heat towards production wells. Addition of a solvating and/or pressurizing fluid to portions of the formation heated by residual heat may facilitate recovery of hydrocarbons without requiring heaters to heat the additional sections. Addition of the fluid may allow for the recovery of hydrocarbons in previously produced sections and/or for the recovery of viscous hydrocarbons in colder sections of the formation.

[1529] In some embodiments, the formation is treated using the in situ heat treatment process for a significant time after the formation has been treated with a drive process. For example, the in situ heat treatment process is used 1 year, 2 years, 3 years, or longer after a formation has been treated using drive processes. After heating the formation for a significant amount of time using heaters and/or injected fluid (for example, steam), a solvation fluid may be added to the heated section and/or portions above and/or below the heated section. The in situ heat treatment process followed by addition of a solvation fluid and/or a pressurizing fluid may be used on formations that have been left dormant after the drive process treatment because further hydrocarbon production using the drive process is not possible and/or not economically feasible. In some embodiments, the solvation fluid and/or the pressurizing fluid is used to increase the amount of heat provided to the formation. In some embodiments, an in situ heat treatment process may be used following addition of the solvation fluid and/or pressurizing fluid to increase the recovery of hydrocarbons from the formation.

[1530] In some embodiments, the solvation fluid forms an in situ solvation fluid mixture. Using the in situ solvation fluid may upgrade the hydrocarbons in the formation. The in situ solvation

fluid may enhance solubilization of hydrocarbons and/or and facilitate moving the hydrocarbons from one portion of the formation to another portion of the formation.

[1531] FIGS. 225 and 226 depict side view representations of embodiments for producing a fluid mixture from the hydrocarbon containing formation. In FIGS. 225 and 226, heaters 412 have substantially horizontal heating sections below overburden 400 in hydrocarbon layer 388 (as shown, the heaters have heating sections that go into and out of the page). Heaters 412 provide heat to first section 938 of hydrocarbon layer 388. Patterns of heaters, such as triangles, squares, rectangles, hexagons, and/or octagons may be used within first section 938. First section 938 may be heated at least to temperatures sufficient to mobilize some hydrocarbons within the first section. A temperature of the heated first section 938 may range from about 200 °C to about 240 °C. In some embodiments, temperature within first section 938 may be increased to a pyrolyzation temperature (for example between 250 °C and 400 °C).

[1532] In certain embodiments, the bottommost heaters are located between about 2 m and about 10 m from the bottom of hydrocarbon layer 388, between about 4 m and about 8 m from the bottom of the hydrocarbon layer, or between about 5 m and about 7 m from the bottom of the hydrocarbon layer. In certain embodiments, production wells 206A are located at a distance from the bottommost heaters 412 that allows heat from the heaters to superimpose over the production wells, but at a distance from the heaters that inhibits coking at the production wells. Production wells 206A may be located a distance from the nearest heater (for example, the bottommost heater) of at most ¾ of the spacing between heaters in the pattern of heaters (for example, the triangular pattern of heaters depicted in FIGS. 225 and 226). In some embodiments, production wells 206A are located a distance from the nearest heater of at most ⅔, at most ½, or at most ⅓ of the spacing between heaters in the pattern of heaters. In certain embodiments, production wells 206A are located between about 2 m and about 10 m from the bottommost heaters, between about 4 m and about 8 m from the bottommost heaters, or between about 5 m and about 7 m from the bottommost heaters. Production wells 206A may be located between about 0.5 m and about 8 m from the bottom of hydrocarbon layer 388, between about 1 m and about 5 m from the bottom of the hydrocarbon layer, or between about 2 m and about 4 m from the bottom of the hydrocarbon layer.

[1533] In some embodiments, formation fluid is produced from first section 938. The formation fluid may be produced through production wells 206A. In some embodiments, the formation fluids drain by gravity to a bottom portion of the layer. The drained fluids may be produced from production wells 206A positioned at the bottom portion of the layer. Production of the formation fluids may continue until a majority of condensable hydrocarbons in the formation fluid are produced. After the majority of the condensable hydrocarbons have been produced, first section

938 heat from heaters 412 may be reduced and/or discontinued to allow a reduction in temperature in the first section. In some embodiments, after the majority of the condensable hydrocarbons have been produced, a pressure of first section 938 may be reduced to a selected pressure after the first section reaches the selected temperature. Selected pressures may range between about 100 kPa and about 1000 kPa, between 200 kPa and 800 kPa, or below a fracture pressure of the formation.

[1534] In some embodiments, the formation fluid produced from production wells 206 includes at least some pyrolyzed hydrocarbons. Some hydrocarbons may be pyrolyzed in portions of first section 938 that are at higher temperatures than a remainder of the first section. For example, portions of formation adjacent to heaters 412 may be at somewhat higher temperatures than the remainder of first section 938. The higher temperature of the formation adjacent to heaters 412 may be sufficient to cause pyrolysis of hydrocarbons. Some of the pyrolysis product may be produced through production wells 206.

[1535] One or more sections may be above and/or below first section 938 (for example, second section 940 and/or third section 942 depicted in FIG. 225). FIG. 226 depicts second section 940 and/or third section 942 adjacent to first section 938. In some embodiments, second section 940 and third section 942 are outside a perimeter defined by the outermost heaters. Some residual heat from first section 938 may transfer to second section 940 and third section 942. In some embodiments, sufficient residual heat is transferred to heat formation fluids to a temperature that allows the fluids to move in second section 940 and/or third section 942 towards productions wells 206. Utilization of residual heat from first section 938 to heat hydrocarbons in second section 940 and/or third section 942 may allow hydrocarbons to be produced from the second section and/or third section without direct heating of these sections. A minimal amount of residual heat to second section 940 and/or third section 942 may be superposition heat from heaters 412. Areas of second section 940 and/or third section 942 that are at a distance greater than the spacing between heaters 412 may be heated by residual heat from first section 938. Second section 940 and/or third section 942 may be heated by conductive and/or convective heat from first section 938. A temperature of the sections heated by residual heat may range from 100 °C to 250 °C, from 150 °C to 225 °C, or from 175 °C to 200 °C depending on the proximity of heaters 412 to second section 940 and/or third section 942.

[1536] In some embodiments, a solvation fluid is provided to first section 938 through injection wells 602A to solvate hydrocarbons within the first section. In some embodiments, solvation fluid is added to first section 938 after a majority of the condensable hydrocarbons have been produced and the first section has cooled. The solvation fluid may solvate and/or dilute the hydrocarbons in first section 938 to form a mixture of condensable hydrocarbons and solvation

fluids. Formation of the mixture may allow for production of hydrocarbons remaining in the first section. Solubilization of hydrocarbons in first section 938 may allow the hydrocarbons to be produced from the first section after heat has been removed from the section. The mixture may be produced through production wells 206A.

[1537] In some embodiments, a solvation fluid is provided to second section 940 and/or third section 942 through injection wells 602B and/or 602C to increase mobilization of hydrocarbons within the second section and/or the third section. The solvation fluid may increase a flow of mobilized hydrocarbons into first section 938. For example, a pressure gradient may be produced between second section 940 and/or third section 942 and first section 938 such that the flow of fluids from the second section and/or the third section to the first section is increased. The solvation fluid may solubilize a portion of the hydrocarbons in second section 940 and/or third section 942 to form a mixture. Solubilization of hydrocarbons in second section 940 and/or third section 942 may allow the hydrocarbons to be produced from the second section and/or third section without direct heating of the sections. In some embodiments, second section 940 and/or third section 942 have been heated from residual heat transferred from first section 938 prior to addition of the solvation fluid. In some embodiments, the solvation fluid is added after second section 940 and/or third section 942 have been heated to a desired temperature by heat from first section 938. In some embodiments, heat from first section 938 and/or heat from the solvation fluid heats section 940 and/or third section 942 to temperatures sufficient to mobilize heavy hydrocarbons in the sections. In some embodiments, section 940 and/or third section 942 are heated to temperatures ranging from 50 °C to 250 °C. In some embodiments, temperatures in section 940 and/or third section 942 are sufficient to mobilize heavy hydrocarbons, thus the solvation fluid may mobilize the heavy hydrocarbons by displacing the heavy hydrocarbons with minimal mixing.

[1538] In some embodiments, water and/or emulsified water may be used as a solvation fluid. Water may be injected into a portion of first section 938, second section 940 and/or third section 942 through injection wells 602. Addition of water to at least a selected section of first section 938, second section 940 and/or third section 942 may water saturate a portion of the sections. The water saturated portions of the selected section may be pressurized by known methods and a water/hydrocarbon mixture may be collected using one or more production wells 206.

[1539] In some embodiments, a hydrocarbon formation and/or sections of a hydrocarbon formation may be heated to a selected temperature using a plurality of heaters. Heat from the heaters may transfer from the heaters so that a section of the formation reaches a selected temperature. Treating the hydrocarbon formation with hot water or "near critical" water may extract and/or solvate hydrocarbons from the formation that have been difficult to produce using

other solvent processes and/or heat treatment processes. Not to be bound by theory, near critical water may solubilize organic material (for example, hydrocarbons) normally not soluble in water. The solubilized and/or mobilized hydrocarbons may be produced from the formation. In other embodiments, the formation is treated with critical or near critical carbon dioxide instead of hot water or near critical water.

[1540] In some embodiments, the hydrocarbon formation or one or more section of the formation may be heated (for example, using heaters) to a temperature ranging from about 100 °C to about 240 °C, from about 150 ° C to about 230 °C, or from about 200 °C to about 220 °C. In some embodiments, the hydrocarbon formation is an oil shale formation. In some embodiments, temperature within the section may be increased to a pyrolyzation temperature (for example, between about 250 °C and about 400 °C). During heating, hydrocarbons may be transformed into lighter hydrocarbons, water, and gas. The hydrocarbons may include bitumen. In some embodiments, kerogen in an oil formation may be transformed into hydrocarbons, water, and gas. During the transformation at least some the kerogen may be transformed into bitumen. In some embodiments, bitumen may flow into heater and/or production wells and solidify. Solidification of the bitumen may decrease connectivity in the heater and/or decrease production of hydrocarbons. In some embodiments, production of the bitumen is difficult due to the flow properties of bitumen.

[1541] In some embodiments, after heating the section to the desired temperature, the bitumen may be treated with hot water and/or a hot solution of water and solvent (for example, a solution of water and aromatics such as phenol and cresol). Hot water (for example, water at temperatures above 275 °C, above 300 °C or above 350°C) and/or a hot solution (for example, a hot solution of water and one or more aromatic compounds such as phenol and/or cresol compounds) may be injected in the formation (for example, an oil shale formation) or sections of the formation through heater, production, and/or injection wells. Pressure and temperature in the formation and/or the wells may be controlled to maintain the most of the water in a liquid phase. For example, the water temperature may range from about 250 °C to about 300 °C at pressures ranging from 5,000 kPa to 15,000 kPa or from 6,000 kPa to 10,000 kPa. Water at these temperatures at pressure may have a dielectric constant of about 20 and a density of about 0.7 grams per cubic centimeter.

[1542] In some embodiments, keeping most of the hot water in a liquid phase may allow the water to enter rock matrix of the formation and mobilize the bitumen and/or extract hydrocarbon fluid from the bitumen. In some embodiments, the hydrocarbon fluid and/or hydrocarbons in the hydrocarbon fluid have a viscosity less than the viscosity of the bitumen. The extracted hydrocarbons and/or mobilized bitumen may be produced from the section and/or be moved into

other sections with solvating fluids and/or pressurizing fluids. Extraction of hydrocarbons from the bitumen and/or solvation of the bitumen with hot water and/or a hot solution may enhance hydrocarbon recovery from the formation. For example, extraction of bitumen may produce hydrocarbons having an API gravity of at least 10°, at least 15° or at least 20°. The hydrocarbons may have a viscosity of at least 100 centipoise at 15 °C. The quality and/or type of the hydrocarbons produced from less heating in combination with hot water extraction may be improved as compared to the quality of hydrocarbons produced at higher temperatures.

[1543] In certain embodiments, first section 938, second section 940 and/or third section 942 may be treated with hydrocarbons (for example, naphtha, kerosene, diesel, vacuum gas oil, or a mixture thereof). In some embodiments, the hydrocarbons have an aromatic content of at least 1% by weight, at least 5% by weight, at least 10% by weight, at least 20% by weight or at least 25% by weight. Hydrocarbons may be injected into a portion of first section 938, second section 940 and/or third section 942 through injection wells 602. In some embodiments, the hydrocarbons are produced from first section 938 and/or other portions of the formation. In certain embodiments, the hydrocarbons are produced from the formation, treated to remove heavy fractions of hydrocarbons (for example, asphaltenes, hydrocarbons having a boiling point of at least 300 °C, of at least 400 °C, at least 500 °C, or at least 600 °C) and the hydrocarbons are re-introduced into the formation. In some embodiments, one section may be treated with hydrocarbons while another section is treated with water. In some embodiments, water treatment of a section may be alternated with hydrocarbon treatment of the section. In some embodiments, a first portion of hydrocarbons having a relatively high boiling range distribution (for example, kerosene and/or diesel) are introduced in one section. A second portion of hydrocarbons having a relatively low boiling range distribution or hydrocarbons of low economic value (for example, propane) may be introduced into the section after the first portion of hydrocarbons. The introduction of hydrocarbons of different boiling range distributions may enhance recovery of the higher boiling hydrocarbons and more economically valuable hydrocarbons through production wells 206.

[1544] In an embodiment, a blend made from hydrocarbon mixtures produced from first section 938 is used as a solvation fluid. The blend may include about 20% by weight light hydrocarbons (or blending agent) or greater (for example, about 50% by weight or about 80% by weight light hydrocarbons) and about 80% by weight heavy hydrocarbons or less (for example, about 50% by weight or about 20% by weight heavy hydrocarbons). The weight percentage of light hydrocarbons and heavy hydrocarbons may vary depending on, for example, a weight distribution (or API gravity) of light and heavy hydrocarbons, an aromatic content of the hydrocarbons, a relative stability of the blend, or a desired API gravity of the blend. For

example, the weight percentage of light hydrocarbons in the blend may at most 50% by weight or at most 20% by weight. In certain embodiments, the weight percentage of light hydrocarbons may be selected to mix the least amount of light hydrocarbons with heavy hydrocarbons that produces a blend with a desired density or viscosity.

[1545] In some embodiments, polymers and/or monomers may be used as solvation fluids. Polymers and/or monomers may solvate and/or drive hydrocarbons to allow mobilization of the hydrocarbons towards one or more production wells. The polymer and/or monomer may reduce the mobility of a water phase in pores of the hydrocarbon containing formation. The reduction of water mobility may allow the hydrocarbons to be more easily mobilized through the hydrocarbon containing formation. Polymers that may be used include, but are not limited to, polyacrylamides, partially hydrolyzed polyacrylamide, polyacrylates, ethylenic copolymers, biopolymers, carboxymethylcellulose, polyvinyl alcohol, polystyrene sulfonates, polyvinylpyrrolidone, AMPS (2-acrylamide-2-methyl propane sulfonate), or combinations thereof. Examples of ethylenic copolymers include copolymers of acrylic acid and acrylamide, acrylic acid and lauryl acrylate, lauryl acrylate and acrylamide. Examples of biopolymers include xanthan gum and guar gum. In some embodiments, polymers may be crosslinked in situ in the hydrocarbon containing formation. In other embodiments, polymers may be generated in situ in the hydrocarbon containing formation. Polymers and polymer preparations for use in oil recovery are described in U.S. Patent Nos. 6,439,308 to Wang; 6,417,268 to Zhang et al.; 5,654,261 to Smith; 5,284,206 to Surles et al.; 5,199,490 to Surles et al.; and 5,103,909 to Morgenthaler et al.

[1546] In some embodiments, the solvation fluid includes one or more nonionic additives (for example, alcohols, ethoxylated alcohols, nonionic surfactants and/or sugar based esters). In some embodiments, the solvation fluid includes one or more anionic surfactants (for example, sulfates, sulfonates, ethoxylated sulfates, and/or phosphates).

[1547] In some embodiments, the solvation fluid includes carbon disulfide. Hydrogen sulfide, in addition to other sulfur compounds produced from the formation, may be converted to carbon disulfide using known methods. Suitable methods may include oxidizing sulfur compounds to sulfur and/or sulfur dioxide, and reacting sulfur and/or sulfur dioxide with carbon and/or a carbon containing compound to form carbon disulfide. The conversion of the sulfur compounds to carbon disulfide and the use of the carbon disulfide for oil recovery are described in U.S. Patent No. 7,426,959 to Wang et al. The carbon disulfide may be introduced into first section 938, second section 940 and/or third section 942 as a solvation fluid.

[1548] In some embodiments, the solvation fluid is a hydrocarbon compound that is capable of donating a hydrogen atom to the formation fluids. In some embodiments, the solvation fluid is

capable of donating hydrogen to at least a portion of the formation fluid, thus forming a mixture of solvating fluid and dehydrogenated solvating fluid mixture. The solvating fluid/dehydrogenated solvating fluid mixture may enhance solvation and/or dissolution of a greater portion of the formation fluids as compared to the initial solvation fluid. Examples of such hydrogen donating solvating fluids include, but are not limited to, tetralin, alkyl substituted tetralin, tetrahydroquinoline, alkyl substituted hydroquinoline, 1,2-dihydronaphthalene, a distillate cut having at least 40% by weight naphthenic aromatic compounds, or mixtures thereof. In some embodiments, the hydrogen donating hydrocarbon compound is tetralin.

[1549] In some embodiments, first section 938, second section 940 and/or third section 942 are heated to a temperature ranging form 175 °C to 350 °C in the presence of the hydrogen donating solvating fluid. At these temperatures at least a portion of the formation fluids may be hydrogenated by hydrogen donated from the hydrogen donating solvation fluid. In some embodiments, the minerals in the formation act as a catalyst for the hydrogenation process so that elevated formation temperatures may not be necessary. Hydrogenation of at least a portion of the formation fluids may upgrade a portion of the formation fluids and form a mixture of upgraded fluids and formation fluids. The mixture may have a reduced viscosity compared to the initial formation fluids. In situ upgrading and the resulting reduction in viscosity may facilitate mobilization and/or recovery of the formation fluids. In situ upgrading products that may be separated from the formation fluids at the surface include, but are not limited to, naphtha, vacuum gas oil, distillate, kerosene, and/or diesel. Dehydrogenation of at least a portion of the hydrogen donating solvent may form a mixture that has increased polarity as compared to the initial hydrogen donating solvent. The increased polarity may enhance solvation or dissolution of a portion of the formation fluids and facilitate production and/or mobilization of the fluids to production wells 206.

[1550] In some embodiments, the hydrogen donating hydrocarbon compound is heated in a surface facility prior to being introduced into first section 938, second section 940 and/or third section 942. For example, the hydrogen donating hydrocarbon compound may be heated to a temperature ranging from 100 °C to about 180 °C, 120 °C to about 170 °C, or from about 130 to 160 °C. Heat from the hot hydrogen donating hydrocarbon compound may facilitate mobilization, recovery and/or hydrogenation of fluids from first section 938, second section 940 and/or third section 942.

[1551] In some embodiments, a pressurizing fluid is provided in second section 940 and/or third section 942 (for example, through injection wells 602B, 602C) to increase mobilization of hydrocarbons within the sections. In some embodiments, a pressurizing fluid is provided to second section 940 and/or third section 942 in combination with the solvation fluid to increase

mobility of hydrocarbons within the formation. The pressurizing fluid may include gases such as carbon dioxide, nitrogen, steam, methane, and/or mixtures thereof. In some embodiments, fluids produced from the formation (for example, combustion gases, heater exhaust gases, or produced formation fluids) may be used as pressurizing fluid.

[1552] Providing a pressurizing fluid may increase a shear rate applied to hydrocarbon fluids in the formation and decrease the viscosity of non-Newtonian hydrocarbon fluids within the formation. In some embodiments, pressurizing fluid is provided to the selected section before significant heating of the formation. Pressurizing fluid injection may increase the volume of the formation available for production. Pressurizing fluid injection may increase a ratio of energy output of the formation (energy content of products produced from the formation) to energy input into the formation (energy costs for treating the formation).

[1553] Providing the pressurizing fluid may increase a pressure in a selected section of the formation. The pressure in the selected section may be maintained below a selected pressure. For example, the pressure may be maintained below about 150 bars absolute, about 100 bars absolute, or about 50 bars absolute. In some embodiments, the pressure may be maintained below about 35 bars absolute. Pressure may be varied depending on a number of factors (for example, desired production rate or an initial viscosity of tar in the formation). Injection of a gas into the formation may result in a viscosity reduction of some of the formation fluids.

[1554] The pressurizing fluid may enhance the pressure gradient in the formation to flow mobilized hydrocarbons into first section 938. In certain embodiments, the production of fluids from first section 938 allows the pressure in second section 940 and/or third section 942 to remain below a selected pressure (for example, a pressure below which fracturing of the overburden and/or the underburden may occur). In some embodiments, second section 940 and/or third section 942 have been heated by heat transfer from first section 938 prior to addition of the pressurizing fluid. In some embodiments, the pressurizing fluid is added after second section 940 and/or third section 942 have been heated to a desired temperature by residual heat from first section 938.

[1555] In some embodiments, pressure is maintained by controlling flow of the pressurizing fluid into the selected section. In other embodiments, the pressure is controlled by varying a location or locations for injecting the pressurizing fluid. In other embodiments, pressure is maintained by controlling a pressure and/or production rate at production wells 206A, 206B and/or 206C. In some embodiments, the pressurized fluid (for example, carbon dioxide) is separated from the produced fluids and re-introduced into the formation. After production has been stopped, the fluid may be sequestered in the formation.

[1556] In certain embodiments, formation fluid is produced from first section 938, second section 940 and/or third section 942. The formation fluid may be produced through production wells 206A, 206B and/or 206C. The formation fluid produced from second section 940 and/or third section 942 may include solvation fluid; hydrocarbons from first section 938, second section 940 and/or third section 942; and/or mixtures thereof.

[1557] Producing fluid from production wells in first section 938 may lower the average pressure in the formation by forming an expansion volume for mobilized fluids in adjacent sections of the formation. Producing fluid from production wells 206 in the first section 938 may establish a pressure gradient in the formation that draws mobilized fluid from second section 940 and/or third section 942 into the first section.

[1558] Hydrocarbons may be produced from first section 938, second section 940 and/or third section 942 such that at least about 30%, at least about 40%, at least about 50%, at least about 60% or at least about 70% by volume of the initial mass of hydrocarbons in the formation are produced. In certain embodiments, additional hydrocarbons may be produced from the formation such that at least about 60%, at least about 70%, or at least about 80% by volume of the initial volume of hydrocarbons in the sections is produced from the formation through the addition of solvation fluid.

[1559] Fluids produced from production wells described herein may be transported through conduits (pipelines) between the formation and treatment facilities or refineries. The produced fluids may be transported through a pipeline to another location for further transportation (for example, the fluids can be transported to a facility at a river or a coast through the pipeline where the fluids can be further transported by tanker to a processing plant or refinery). Incorporation of selected solvation fluids and/or other produced fluids (for example, aromatic hydrocarbons) in the produced formation fluid may stabilize the formation fluid during transportation. In some embodiments, the solvation fluid is separated from the formation fluids after transportation to treatment facilities. In some embodiments, at least a portion of the solvation fluid is separated from the formation fluids prior to transportation. In some embodiments, the fluids produced prior to solvent treatment include heavy hydrocarbons.

[1560] In some embodiments, the produced fluids may include at least 85% hydrocarbon liquids by volume and at most 15% gases by volume, at least 90% hydrocarbon liquids by volume and at most 10% gases by volume, or at least 95% hydrocarbon liquids by volume and at most 5% gases by volume. In some embodiments, the mixture produced after solvent and/or pressure treatment includes solvation fluids, gases, bitumen, visbroken fluids, pyrolyzed fluids, or combinations thereof. The mixture may be separated into heavy hydrocarbon liquids, solvation fluid and/or

gases. In some embodiments the heavy hydrocarbon liquids, solvation fluid and/or pressuring fluid (for example, carbon dioxide) are re-injected in another section of the formation.

[1561] The heavy hydrocarbon liquids separated from the mixture may have an API gravity of between 10° and 25°, between 15° and 24°, or between 19° and 23°. In some embodiments, the separated hydrocarbon liquids may have an API gravity between 19° and 25°, between 20° and 24°, or between 21° and 23°. A viscosity of the separated hydrocarbon liquids may be at most 350 cp at 5° C. A P-value of the separated hydrocarbon liquids may be at least 1.1, at least 1.5 or at least 2.0. The separated hydrocarbon liquids may have a bromine number of at most 3% and/or a CAPP number of at most 2%. In some embodiments, the separated hydrocarbon liquids have an API gravity between 19° and 25°, a viscosity ranging at most 350 cp at 5 °C, a P-value of at least 1.1, a CAPP number of at most 2% as 1-decene equivalent, and/or a bromine number of at most 2%.

[1562] Some hydrocarbon containing formations, such as oil shale formations, may include nahcolite, trona, dawsonite, and/or other minerals within the formation. In some embodiments, nahcolite is contained in partially unleached or unleached portions of the formation. Unleached portions of the formation are parts of the formation where minerals have not been removed by groundwater in the formation. For example, in the Piceance basin in Colorado, U.S.A., unleached oil shale is found below a depth of about 500 m below grade. Deep unleached oil shale formations in the Piceance basin center tend to be relatively rich in hydrocarbons. For example, about 0.10 liters to about 0.15 liters of oil per kilogram (L/kg) of oil shale may be producible from an unleached oil shale formation.

[1563] Nahcolite is a mineral that includes sodium bicarbonate ($NaHCO_3$). Nahcolite may be found in formations in the Green River lakebeds in Colorado, U.S.A. In some embodiments, at least about 5 weight %, at least about 10 weight %, or at least about 20 weight % nahcolite may be present in the formation. Dawsonite is a mineral that includes sodium aluminum carbonate ($NaAl(CO_3)(OH)_2$). Dawsonite is typically present in the formation at weight percents greater than about 2 weight % or, in some embodiments, greater than about 5 weight %. Nahcolite and/or dawsonite may dissociate at temperatures used in an in situ heat treatment process. The dissociation is strongly endothermic and may produce large amounts of carbon dioxide.

[1564] Nahcolite and/or dawsonite may be solution mined prior to, during, and/or following treatment of the formation in situ to avoid dissociation reactions and/or to obtain desired chemical compounds. In certain embodiments, hot water or steam is used to dissolve nahcolite in situ to form an aqueous sodium bicarbonate solution before the in situ heat treatment process is used to process hydrocarbons in the formation. Nahcolite may form sodium ions (Na^+) and bicarbonate ions (HCO_3^-) in aqueous solution. The solution may be produced from the

formation through production wells, thus avoiding dissociation reactions during the in situ heat treatment process. In some embodiments, dawsonite is thermally decomposed to alumina during the in situ heat treatment process for treating hydrocarbons in the formation. The alumina is solution mined after completion of the in situ heat treatment process.

[1565] Production wells and/or injection wells used for solution mining and/or for in situ heat treatment processes may include smart well technology. The smart well technology allows the first fluid to be introduced at a desired zone in the formation. The smart well technology allows the second fluid to be removed from a desired zone of the formation.

[1566] Formations that include nahcolite and/or dawsonite may be treated using the in situ heat treatment process. A perimeter barrier may be formed around the portion of the formation to be treated. The perimeter barrier may inhibit migration of water into the treatment area. During solution mining and/or the in situ heat treatment process, the perimeter barrier may inhibit migration of dissolved minerals and formation fluid from the treatment area. During initial heating, a portion of the formation to be treated may be raised to a temperature below the dissociation temperature of the nahcolite. The temperature may be at most about 90 °C, or in some embodiments, at most about 80 °C. The temperature may be any temperature that increases the solvation rate of nahcolite in water, but is also below a temperature at which nahcolite dissociates (above about 95 °C at atmospheric pressure).

[1567] A first fluid may be injected into the heated portion. The first fluid may include water, brine, steam, or other fluids that form a solution with nahcolite and/or dawsonite. The first fluid may be at an increased temperature, for example, about 90 °C, about 95 °C, or about 100 °C. The increased temperature may be similar to the temperature of the portion of the formation.

[1568] In some embodiments, the first fluid is injected at an increased temperature into a portion of the formation that has not been heated by heat sources. The increased temperature may be a temperature below a boiling point of the first fluid, for example, about 90 °C for water. Providing the first fluid at an increased temperature increases a temperature of a portion of the formation. In certain embodiments, additional heat may be provided from one or more heat sources in the formation during and/or after injection of the first fluid.

[1569] In other embodiments, the first fluid is or includes steam. The steam may be produced by forming steam in a previously heated portion of the formation (for example, by passing water through u-shaped wellbores that have been used to heat the formation), by heat exchange with fluids produced from the formation, and/or by generating steam in standard steam production facilities. In some embodiments, the first fluid may be fluid introduced directly into a hot portion of the portion and produced from the hot portion of the formation. The first fluid may then be used as the first fluid for solution mining.

[1570] In some embodiments, heat from a hot previously treated portion of the formation is used to heat water, brine, and/or steam used for solution mining a new portion of the formation. Heat transfer fluid may be introduced into the hot previously treated portion of the formation. The heat transfer fluid may be water, steam, carbon dioxide, and/or other fluids. Heat may transfer from the hot formation to the heat transfer fluid. The heat transfer fluid is produced from the formation through production wells. The heat transfer fluid is sent to a heat exchanger. The heat exchanger may heat water, brine, and/or steam used as the first fluid to solution mine the new portion of the formation. The heat transfer fluid may be reintroduced into the heated portion of the formation to produce additional hot heat transfer fluid. In some embodiments, heat transfer fluid produced from the formation is treated to remove hydrocarbons or other materials before being reintroduced into the formation as part of a remediation process for the heated portion of the formation.

[1571] Steam injected for solution mining may have a temperature below the pyrolysis temperature of hydrocarbons in the formation. Injected steam may be at a temperature below 250 °C, below 300 °C, or below 400 °C. The injected steam may be at a temperature of at least 150 °C, at least 135 °C, or at least 125 °C. Injecting steam at pyrolysis temperatures may cause problems as hydrocarbons pyrolyze and hydrocarbon fines mix with the steam. The mixture of fines and steam may reduce permeability and/or cause plugging of production wells and the formation. Thus, the injected steam temperature is selected to inhibit plugging of the formation and/or wells in the formation.

[1572] The temperature of the first fluid may be varied during the solution mining process. As the solution mining progresses and the nahcolite being solution mined is farther away from the injection point, the first fluid temperature may be increased so that steam and/or water that reaches the nahcolite to be solution mined is at an elevated temperature below the dissociation temperature of the nahcolite. The steam and/or water that reaches the nahcolite is also at a temperature below a temperature that promotes plugging of the formation and/or wells in the formation (for example, the pyrolysis temperature of hydrocarbons in the formation).

[1573] A second fluid may be produced from the formation following injection of the first fluid into the formation. The second fluid may include material dissolved in the first fluid. For example, the second fluid may include carbonic acid or other hydrated carbonate compounds formed from the dissolution of nahcolite in the first fluid. The second fluid may also include minerals and/or metals. The minerals and/or metals may include sodium, aluminum, phosphorus, and other elements.

[1574] Solution mining the formation before the in situ heat treatment process allows initial heating of the formation to be provided by heat transfer from the first fluid used during solution

mining. Solution mining nahcolite or other minerals that decompose or dissociate by means of endothermic reactions before the in situ heat treatment process avoids having energy supplied to heat the formation being used to support these endothermic reactions. Solution mining allows for production of minerals with commercial value. Removing nahcolite or other minerals before the in situ heat treatment process removes mass from the formation. Thus, less mass is present in the formation that needs to be heated to higher temperatures and heating the formation to higher temperatures may be achieved more quickly and/or more efficiently. Removing mass from the formation also may increase the permeability of the formation. Increasing the permeability may reduce the number of production wells needed for the in situ heat treatment process. In certain embodiments, solution mining before the in situ heat treatment process reduces the time delay between startup of heating of the formation and production of hydrocarbons by two years or more.

[1575] FIG. 227 depicts an embodiment of solution mining well 944. Solution mining well 944 may include insulated portion 926, input 946, packer 948, and return 950. Insulated portion 926 may be adjacent to overburden 400 of the formation. In some embodiments, insulated portion 926 is low conductivity cement. The cement may be low density, low conductivity vermiculite cement or foam cement. Input 946 may direct the first fluid to treatment area 730. Perforations or other types of openings in input 946 allow the first fluid to contact formation material in treatment area 730. Packer 948 may be a bottom seal for input 946. First fluid passes through input 946 into the formation. First fluid dissolves minerals and becomes second fluid. The second fluid may be denser than the first fluid. An entrance into return 950 is typically located below the perforations or openings that allow the first fluid to enter the formation. Second fluid flows to return 950. The second fluid is removed from the formation through return 950.

[1576] FIG. 228 depicts a representation of an embodiment of solution mining well 944. Solution mining well 944 may include input 946 and return 950 in casing 952. Input 946 and/or return 950 may be coiled tubing.

[1577] FIG. 229 depicts a representation of an embodiment of solution mining well 944. Insulating portions 926 may surround return 950. Input 946 may be positioned in return 950. In some embodiments, input 946 may introduce the first fluid into the treatment area below the entry point into return 950. In some embodiments, crossovers may be used to direct first fluid flow and second fluid flow so that first fluid is introduced into the formation from input 946 above the entry point of second fluid into return 950.

[1578] FIG. 230 depicts an elevational view of an embodiment of wells used for solution mining and/or for an in situ heat treatment process. Solution mining wells 944 may be placed in the formation in an equilateral triangle pattern. In some embodiments, the spacing between solution

mining wells 944 may be about 36 m. Other spacings may be used. Heat sources 202 may also be placed in an equilateral triangle pattern. Solution mining wells 944 substitute for certain heat sources of the pattern. In the shown embodiment, the spacing between heat sources 202 is about 9 m. The ratio of solution mining well spacing to heat source spacing is 4. Other ratios may be used if desired. After solution mining is complete, solution mining wells 944 may be used as production wells for the in situ heat treatment process.

[1579] In some formations, a portion of the formation with unleached minerals may be below a leached portion of the formation. The unleached portion may be thick and substantially impermeable. A treatment area may be formed in the unleached portion. Unleached portion of the formation to the sides, above and/or below the treatment area may be used as barriers to fluid flow into and out of the treatment area. A first treatment area may be solution mined to remove minerals, increase permeability in the treatment area, and/or increase the richness of the hydrocarbons in the treatment area. After solution mining the first treatment area, in situ heat treatment may be used to treat a second treatment area. In some embodiments, the second treatment area is the same as the first treatment area. In some embodiments, the second treatment has a smaller volume than the first treatment area so that heat provided by outermost heat sources to the formation do not raise the temperature of unleached portions of the formation to the dissociation temperature of the minerals in the unleached portions.

[1580] In some embodiments, a leached or partially leached portion of the formation above an unleached portion of the formation may include significant amounts of hydrocarbon materials. An in situ heating process may be used to produce hydrocarbon fluids from the unleached portions and the leached or partially leached portions of the formation. FIG. 231 depicts a representation of a formation with unleached zone 954 below leached zone 956. Unleached zone 954 may have an initial permeability before solution mining of less than 0.1 millidarcy. Solution mining wells 944 may be placed in the formation. Solution mining wells 944 may include smart well technology that allows the position of first fluid entrance into the formation and second flow entrance into the solution mining wells to be changed. Solution mining wells 944 may be used to form first treatment area 730' in unleached zone 954. Unleached zone 954 may initially be substantially impermeable. Unleached portions of the formation may form a top barrier and side barriers around first treatment area 730'. After solution mining first treatment area 730', the portions of solution mining wells 944 adjacent to the first treatment area may be converted to production wells and/or heater wells.

[1581] Heat sources 202 in first treatment area 730' may be used to heat the first treatment area to pyrolysis temperatures. In some embodiments, one or more heat sources 202 are placed in the formation before first treatment area 730' is solution mined. The heat sources may be used to

provide initial heating to the formation to raise the temperature of the formation and/or to test the functionality of the heat sources. In some embodiments, one or more heat sources are installed during solution mining of the first treatment area, or after solution mining is completed. After solution mining, heat sources 202 may be used to raise the temperature of at least a portion of first treatment area 730' above the pyrolysis and/or mobilization temperature of hydrocarbons in the formation to result in the generation of mobile hydrocarbons in the first treatment area.

[1582] Barrier wells 200 may be introduced into the formation. Ends of barrier wells 200 may extend into and terminate in unleached zone 954. Unleached zone 954 may be impermeable. In some embodiments, barrier wells 200 are freeze wells. Barrier wells 200 may be used to form a barrier to fluid flow into or out of unleached zone 956. Barrier wells 200, overburden 400, and the unleached material above first treatment area 730' may define second treatment area 730". In some embodiments, a first fluid may be introduced into second treatment area 730" through solution mining wells 944 to raise the initial temperature of the formation in second treatment area 730" and remove any residual soluble minerals from the second treatment area. In some embodiments, the top barrier above first treatment area 730' may be solution mined to remove minerals and combine first treatment area 730' and second treatment area 730" into one treatment area. After solution mining, heat sources may be activated to heat the treatment area to pyrolysis temperatures.

[1583] FIG. 232 depicts an embodiment for solution mining the formation. Barrier 958 (for example, a frozen barrier and/or a grout barrier) may be formed around a perimeter of treatment area 730 of the formation. The footprint defined by the barrier may have any desired shape such as circular, square, rectangular, polygonal, or irregular shape. Barrier 958 may be any barrier formed to inhibit the flow of fluid into or out of treatment area 730. For example, barrier 958 may include one or more freeze wells that inhibit water flow through the barrier. Barrier 958 may be formed using one or more barrier wells 200. Formation of barrier 958 may be monitored using monitor wells 960 and/or by monitoring devices placed in barrier wells 200.

[1584] Water inside treatment area 730 may be pumped out of the treatment area through injection wells 602 and/or production wells 206. In certain embodiments, injection wells 602 are used as production wells 206 and vice versa (the wells are used as both injection wells and production wells). Water may be pumped out until a production rate of water is low or stops.

[1585] Heat may be provided to treatment area 730 from heat sources 202. Heat sources may be operated at temperatures that do not result in the pyrolysis of hydrocarbons in the formation adjacent to the heat sources. In some embodiments, treatment area 730 is heated to a temperature from about 90 °C to about 120 °C (for example, a temperature of about 90 °C, 95 °C, 100 °C, 110 °C, or 120 °C). In certain embodiments, heat is provided to treatment area 730 from the first

fluid injected into the formation. The first fluid may be injected at a temperature from about 90 °C to about 120 °C (for example, a temperature of about 90 °C, 95 °C, 100 °C, 110 °C, or 120 °C). In some embodiments, heat sources 202 are installed in treatment area 730 after the treatment area is solution mined. In some embodiments, some heat is provided from heaters placed in injection wells 602 and/or production wells 206. A temperature of treatment area 730 may be monitored using temperature measurement devices placed in monitoring wells 960 and/or temperature measurement devices in injection wells 602, production wells 206, and/or heat sources 202.

[1586] The first fluid is injected through one or more injection wells 602. In some embodiments, the first fluid is hot water. The first fluid may mix and/or combine with non-hydrocarbon material that is soluble in the first fluid, such as nahcolite, to produce a second fluid. The second fluid may be removed from the treatment area through injection wells 602, production wells 206, and/or heat sources 202. Injection wells 602, production wells 206, and/or heat sources 202 may be heated during removal of the second fluid. Heating one or more wells during removal of the second fluid may maintain the temperature of the fluid during removal of the fluid from the treatment area above a desired value. After producing a desired amount of the soluble non-hydrocarbon material from treatment area 730, solution remaining within the treatment area may be removed from the treatment area through injection wells 602, production wells 206, and/or heat sources 202. The desired amount of the soluble non-hydrocarbon material may be less than half of the soluble non-hydrocarbon material, a majority of the soluble non-hydrocarbon material, substantially all of the soluble non-hydrocarbon material, or all of the soluble non-hydrocarbon material. Removing soluble non-hydrocarbon material may produce a relatively high permeability treatment area 730.

[1587] Hydrocarbons within treatment area 730 may be pyrolyzed and/or produced using the in situ heat treatment process following removal of soluble non-hydrocarbon materials. The relatively high permeability treatment area allows for easy movement of hydrocarbon fluids in the formation during in situ heat treatment processing. The relatively high permeability treatment area provides an enhanced collection area for pyrolyzed and mobilized fluids in the formation. During the in situ heat treatment process, heat may be provided to treatment area 730 from heat sources 202. A mixture of hydrocarbons may be produced from the formation through production wells 206 and/or heat sources 202. In certain embodiments, injection wells 602 are used as either production wells and/or heater wells during the in situ heat treatment process.

[1588] In some embodiments, a controlled amount of oxidant (for example, air and/or oxygen) is provided to treatment area 730 at or near heat sources 202 when a temperature in the formation is above a temperature sufficient to support oxidation of hydrocarbons. At such a temperature, the

oxidant reacts with the hydrocarbons to provide heat in addition to heat provided by electrical heaters in heat sources 202. The controlled amount of oxidant may facilitate oxidation of hydrocarbons in the formation to provide additional heat for pyrolyzing hydrocarbons in the formation. The oxidant may more easily flow through treatment area 730 because of the increased permeability of the treatment area after removal of the non-hydrocarbon materials. The oxidant may be provided in a controlled manner to control the heating of the formation. The amount of oxidant provided is controlled so that uncontrolled heating of the formation is avoided. Excess oxidant and combustion products may flow to production wells in treatment area 730.

[1589] Following the in situ heat treatment process, treatment area 730 may be cooled by introducing water to produce steam from the hot portion of the formation. Introduction of water to produce steam may vaporize some hydrocarbons remaining in the formation. Water may be injected through injection wells 602. The injected water may cool the formation. The remaining hydrocarbons and generated steam may be produced through production wells 206 and/or heat sources 202. Treatment area 730 may be cooled to a temperature near the boiling point of water. The steam produced from the formation may be used to heat a first fluid used to solution mine another portion of the formation.

[1590] Treatment area 730 may be further cooled to a temperature at which water will condense in the formation. Water and/or solvent may be introduced into and be removed from the treatment area. Removing the condensed water and/or solvent from treatment area 730 may remove any additional soluble material remaining in the treatment area. The water and/or solvent may entrain non-soluble fluid present in the formation. Fluid may be pumped out of treatment area 730 through production well 206 and/or heat sources 202. The injection and removal of water and/or solvent may be repeated until a desired water quality within treatment area 730 is achieved. Water quality may be measured at the injection wells, heat sources 202, and/or production wells. The water quality may substantially match or exceed the water quality of treatment area 730 prior to treatment.

[1591] In some embodiments, treatment area 730 may include a leached zone located above an unleached zone. The leached zone may have been leached naturally and/or by a separate leaching process. In certain embodiments, the unleached zone may be at a depth of at least about 500 m. A thickness of the unleached zone may be between about 100 m and about 500 m. However, the depth and thickness of the unleached zone may vary depending on, for example, a location of treatment area 730 and/or the type of formation. In certain embodiments, the first fluid is injected into the unleached zone below the leached zone. Heat may also be provided into the unleached zone.

[1592] In certain embodiments, a section of a formation may be left untreated by solution mining and/or unleached. The unleached section may be proximate a selected section of the formation that has been leached and/or solution mined by providing the first fluid as described above. The unleached section may inhibit the flow of water into the selected section. In some embodiments, more than one unleached section may be proximate a selected section.

[1593] Nahcolite may be present in the formation in layers or beds. Prior to solution mining, such layers may have little or no permeability. In certain embodiments, solution mining layered or bedded nahcolite from the formation causes vertical shifting in the formation. FIG. 233 depicts an embodiment of a formation with nahcolite layers in the formation below overburden 400 and before solution mining nahcolite from the formation. Hydrocarbon layers 388A have substantially no nahcolite and hydrocarbon layers 388B have nahcolite. FIG. 234 depicts the formation of FIG. 233 after the nahcolite has been solution mined. Layers 388B have collapsed due to the removal of the nahcolite from the layers. The collapsing of layers 388B causes compaction of the layers and vertical shifting of the formation. The hydrocarbon richness of layers 388B is increased after compaction of the layers. In addition, the permeability of layers 388B may remain relatively high after compaction due to removal of the nahcolite. The permeability may be more than 5 darcy, more than 1 darcy, or more than 0.5 darcy after vertical shifting. The permeability may provide fluid flow paths to production wells when the formation is treated using an in situ heat treatment process. The increased permeability may allow for a large spacing between production wells. Distances between production wells for the in situ heat treatment system after solution mining may be greater than 10 m, greater than 20 m, or greater than 30 meters. Heater wells may be placed in the formation after removal of nahcolite and the subsequent vertical shifting. Forming heater wellbores and/or installing heaters in the formation after the vertical shifting protects the heaters from being damaged due to the vertical shifting.

[1594] In certain embodiments, removing nahcolite from the formation interconnects two or more wells in the formation. Removing nahcolite from zones in the formation may increase the permeability in the zones. Some zones may have more nahcolite than others and become more permeable as the nahcolite is removed. At a certain time, zones with the increased permeability may interconnect two or more wells (for example, injection wells or production wells) in the formation.

[1595] FIG. 235 depicts an embodiment of two injection wells interconnected by a zone that has been solution mined to remove nahcolite from the zone. Solution mining wells 944 are used to solution mine hydrocarbon layer 388, which contains nahcolite. During the initial portion of the solution mining process, solution mining wells 944 are used to inject water and/or other fluids, and to produce dissolved nahcolite fluids from the formation. Each solution mining well 944 is

used to inject water and produce fluid from a near wellbore region as the permeability of hydrocarbon layer is not sufficient to allow fluid to flow between the injection wells. In certain embodiments, zone 962 has more nahcolite than other portions of hydrocarbon layer 388. With increased nahcolite removal from zone 962, the permeability of the zone may increase. The permeability increases from the wellbores outwards as nahcolite is removed from zone 962. At some point during solution mining of the formation, the permeability of zone 962 increases to allow solution mining wells 944 to become interconnected such that fluid will flow between the wells. At this time, one solution mining well 944 may be used to inject water while the other solution mining well is used to produce fluids from the formation in a continuous process. Injecting in one well and producing from a second well may be more economical and more efficient in removing nahcolite, as compared to injecting and producing through the same well. In some embodiments, additional wells may be drilled into zone 962 and/or hydrocarbon layer 388 in addition to solution mining wells 944. The additional wells may be used to circulate additional water and/or to produce fluids from the formation. The wells may later be used as heater wells and/or production wells for the in situ heat treatment process treatment of hydrocarbon layer 388.

[1596] In some embodiments, a treatment area has nahcolite beds above and/or below the treatment area. The nahcolite beds may be relatively thin (for example, about 5 m to about 10 m in thickness). In an embodiment, the nahcolite beds are solution mined using horizontal solution mining wells in the nahcolite beds. The nahcolite beds may be solution mined in a short amount of time (for example, in less than 6 months). After solution mining of the nahcolite beds, the treatment area and the nahcolite beds may be heated using one or more heaters. The heaters may be placed either vertically, horizontally, or at other angles within the treatment area and the nahcolite beds. The nahcolite beds and the treatment area may then undergo the in situ heat treatment process.

[1597] In some embodiments, the solution mining wells in the nahcolite beds are converted to production wells. The production wells may be used to produce fluids during the in situ heat treatment process. Production wells in the nahcolite bed above the treatment area may be used to produce vapors or gas (for example, gas hydrocarbons) from the formation. Production wells in the nahcolite bed below the treatment area may be used to produce liquids (for example, liquid hydrocarbons) from the formation.

[1598] FIG. 236 depicts a representation of an embodiment for treating a portion of a formation having hydrocarbon containing layer 388 between upper nahcolite bed 964 and lower nahcolite bed 964'. In an embodiment, nahcolite beds 964, 964' have thicknesses of about 5 m and include relatively large amounts of nahcolite (for example, over about 50 weight percent nahcolite). In

the embodiment, hydrocarbon containing layer 388 is at a depth of over 595 meters below the surface, has a thickness of 40 m or more and has oil shale with an average richness of over 100 liters per metric ton. Hydrocarbon containing layer 388 may contain relatively little nahcolite, though the hydrocarbon containing layer may contain some seams of nahcolite typically with thicknesses less than 3 m.

[1599] Solution mining wells 944 may be formed in nahcolite beds 964, 964' (into and out of the page as depicted in FIG. 236). FIG. 237 depicts a representation of a portion of the formation that is orthogonal to the formation depicted in FIG. 236 and passes through one of solution mining wells 944 in nahcolite bed 964. Solution mining wells 944 may be spaced apart by 25 m or more. Hot water and/or steam may be circulated into the formation from solution mining wells 944 to dissolve nahcolite in nahcolite beds 964, 964'. Dissolved nahcolite may be produced from the formation through solution mining wells 944. After completion of solution mining, production liners may be installed in one or more of the solution mining wells 944 and the solution mining wells may be converted to production wells for an in situ heat treatment process used to produce hydrocarbons from hydrocarbon containing layer 388.

[1600] Before, during or after solution mining of nahcolite beds 964, 964', heater wellbores 490 may be formed in the formation in a pattern (for example, in a triangular pattern as depicted in FIG. 237 with wellbores going into and out of the page). As depicted in FIG. 236, portions of heater wellbores 490 may pass through nahcolite bed 964. Portions of heater wellbores 490 may pass into or through nahcolite bed 964'. Heaters wellbores 490 may be oriented at an angle (as depicted in FIG. 236), oriented vertically, or oriented substantially horizontally if the nahcolite layers dip. Heaters may be placed in heater wellbores 490. Heating sections of the heaters may provide heat to hydrocarbon containing layer 388. The wellbore pattern may allow superposition of heat from the heaters to raise the temperature of hydrocarbon containing layer 388 to a desired temperature in a reasonable amount of time.

[1601] Packers, cement, or other sealing systems may be used to inhibit formation fluid from moving up wellbores 490 past an upper portion of nahcolite bed 964 if formation above the nahcolite bed is not to be treated. Packers, cement, or other sealing systems may be used to inhibit formation fluid past a lower portion of nahcolite bed 964' if formation below the nahcolite bed is not to be treated and wellbores 490 extend past the nahcolite bed.

[1602] After solution mining of nahcolite beds 964, 964' is completed, heaters in heater wellbores 490 may raise the temperature of hydrocarbon containing layer 388 to mobilization and/or pyrolysis temperatures. Formation fluid generated from hydrocarbon containing layer 388 may be produced from the formation through converted solution mining wells 944. Initially, vaporized formation fluid may flow along heater wellbores 490 to converted solution mining

wells 944 in nahcolite bed 964. Initially, liquid formation fluid may flow along heater wellbores 490 to converted solution mining wells 944 in nahcolite bed 964'. As heating is continued, fractures caused by heating and/or increased permeability due to the removal of material may provide additional fluid pathways to nahcolite beds 964, 964' so that formation fluid generated from hydrocarbon containing layer 388 may be produced from converted solution mining wells 944 in the nahcolite beds. Converted solution mining wells 944 in nahcolite bed 964 may be used to primarily produce vaporized formation fluids. Converted solution mining wells 944 in nahcolite bed 964' may be used to primarily produce liquid formation fluid.

[1603] In some embodiments, the second fluid produced from the formation during solution mining is used to produce sodium bicarbonate. Sodium bicarbonate may be used in the food and pharmaceutical industries, in leather tanning, in fire retardation, in wastewater treatment, and in flue gas treatment (flue gas desulphurization and hydrogen chloride reduction). The second fluid may be kept pressurized and at an elevated temperature when removed from the formation. The second fluid may be cooled in a crystallizer to precipitate sodium bicarbonate.

[1604] In some embodiments, the second fluid produced from the formation during solution mining is used to produce sodium carbonate, which is also referred to as soda ash. Sodium carbonate may be used in the manufacture of glass, in the manufacture of detergents, in water purification, polymer production, tanning, paper manufacturing, effluent neutralization, metal refining, sugar extraction, and/or cement manufacturing. The second fluid removed from the formation may be heated in a treatment facility to form sodium carbonate (soda ash) and/or sodium carbonate brine. Heating sodium bicarbonate will form sodium carbonate according to the equation:

(EQN. 10) $2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$.

[1605] In certain embodiments, the heat for heating the sodium bicarbonate is provided using heat from the formation. For example, a heat exchanger that uses steam produced from the water introduced into the hot formation may be used to heat the second fluid to dissociation temperatures of the sodium bicarbonate. In some embodiments, the second fluid is circulated through the formation to utilize heat in the formation for further reaction. Steam and/or hot water may also be added to facilitate circulation. The second fluid may be circulated through a heated portion of the formation that has been subjected to the in situ heat treatment process to produce hydrocarbons from the formation. At least a portion of the carbon dioxide generated during sodium carbonate dissociation may be adsorbed on carbon that remains in the formation after the in situ heat treatment process. In some embodiments, the second fluid is circulated through conduits previously used to heat the formation.

[1606] In some embodiments, higher temperatures are used in the formation (for example, above about 120 °C, above about 130 °C, above about 150 °C, or below about 250 °C) during solution mining of nahcolite. The first fluid is introduced into the formation under pressure sufficient to inhibit sodium bicarbonate from dissociating to produce carbon dioxide. The pressure in the formation may be maintained at sufficiently high pressures to inhibit such nahcolite dissociation but below pressures that would result in fracturing the formation. In addition, the pressure in the formation may be maintained high enough to inhibit steam formation if hot water is being introduced in the formation. In some embodiments, a portion of the nahcolite may begin to decompose in situ. In such cases, nahcolite is removed from the formation as soda ash. If soda ash is produced from solution mining of nahcolite, the soda ash may be transported to a separate facility for treatment. The soda ash may be transported through a pipeline to the separate facility.

[1607] As described above, in certain embodiments, following removal of nahcolite from the formation, the formation is treated using the in situ heat treatment process to produce formation fluids from the formation. In some embodiments, the formation is treating using the in situ heat treatment process before solution mining nahcolite from the formation. The nahcolite may be converted to sodium carbonate (from sodium bicarbonate) during the in situ heat treatment process. The sodium carbonate may be solution mined as described above for solution mining nahcolite prior to the in situ heat treatment process.

[1608] In some formations, dawsonite is present in the formation. Dawsonite within the heated portion of the formation decomposes during heating of the formation to pyrolysis temperature. Dawsonite typically decomposes at temperatures above 270 °C according to the reaction:

(EQN. 11) $2NaAl(OH)_2CO_3 \rightarrow Na_2CO_3 + Al_2O_3 + 2H_2O + CO_2$.

[1609] Sodium carbonate may be removed from the formation by solution mining the formation with water or other fluid into which sodium carbonate is soluble. In certain embodiments, alumina formed by dawsonite decomposition is solution mined using a chelating agent. The chelating agent may be injected through injection wells, production wells, and/or heater wells used for solution mining nahcolite and/or the in situ heat treatment process (for example, injection wells 602, production wells 206, and/or heat sources 202 depicted in FIG. 232). The chelating agent may be an aqueous acid. In certain embodiments, the chelating agent is EDTA (ethylenediaminetetraacetic acid). Other examples of possible chelating agents include, but are not limited to, ethylenediamine, porphyrins, dimercaprol, nitrilotriacetic acid, diethylenetriaminepentaacetic acid, phosphoric acids, acetic acid, acetoxy benzoic acids, nicotinic acid, pyruvic acid, citric acid, tartaric acid, malonic acid, imidizole, ascorbic acid, phenols, hydroxy ketones, sebacic acid, and boric acid. The mixture of chelating agent and alumina may be produced through production wells or other wells used for solution mining

and/or the in situ heat treatment process (for example, injection wells 602, production wells 206, and/or heat sources 202, which are depicted in FIG. 232). The alumina may be separated from the chelating agent in a treatment facility. The recovered chelating agent may be recirculated back to the formation to solution mine more alumina.

[1610] In some embodiments, alumina within the formation may be solution mined using a basic fluid after the in situ heat treatment process. Basic fluids include, but are not limited to, sodium hydroxide, ammonia, magnesium hydroxide, magnesium carbonate, sodium carbonate, potassium carbonate, pyridine, and amines. In an embodiment, sodium carbonate brine, such as 0.5 Normal Na_2CO_3, is used to solution mine alumina. Sodium carbonate brine may be obtained from solution mining nahcolite from the formation. Obtaining the basic fluid by solution mining the nahcolite may significantly reduce costs associated with obtaining the basic fluid. The basic fluid may be injected into the formation through a heater well and/or an injection well. The basic fluid may combine with alumina to form an alumina solution that is removed from the formation. The alumina solution may be removed through a heater well, injection well, or production well.

[1611] Alumina may be extracted from the alumina solution in a treatment facility. In an embodiment, carbon dioxide is bubbled through the alumina solution to precipitate the alumina from the basic fluid. Carbon dioxide may be obtained from dissociation of nahcolite, from the in situ heat treatment process, or from decomposition of the dawsonite during the in situ heat treatment process.

[1612] In certain embodiments, a formation may include portions that are significantly rich in either nahcolite or dawsonite only. For example, a formation may contain significant amounts of nahcolite (for example, at least about 20 weight %, at least about 30 weight %, or at least about 40 weight %) in a depocenter of the formation. The depocenter may contain only about 5 weight % or less dawsonite on average. However, in bottom layers of the formation, a weight percent of dawsonite may be about 10 weight % or even as high as about 25 weight %. In such formations, it may be advantageous to solution mine for nahcolite only in nahcolite-rich areas, such as the depocenter, and solution mine for dawsonite only in the dawsonite-rich areas, such as the bottom layers. This selective solution mining may significantly reduce fluid costs, heating costs, and/or equipment costs associated with operating the solution mining process.

[1613] In certain formations, dawsonite composition varies between layers in the formation. For example, some layers of the formation may have dawsonite and some layers may not. In certain embodiments, more heat is provided to layers with more dawsonite than to layers with less dawsonite. Tailoring heat input to provide more heat to certain dawsonite layers more uniformly heats the formation as the reaction to decompose dawsonite absorbs some of the heat intended for pyrolyzing hydrocarbons. FIG. 238 depicts an embodiment for heating a formation with

dawsonite in the formation. Hydrocarbon layer 388 may be cored to assess the dawsonite composition of the hydrocarbon layer. The mineral composition may be assessed using, for example, FTIR (Fourier transform infrared spectroscopy) or x-ray diffraction. Assessing the core composition may also assess the nahcolite composition of the core. After assessing the dawsonite composition, heater 412 may be placed in wellbore 490. Heater 412 includes sections to provide more heat to hydrocarbon layers with more dawsonite in the layers (hydrocarbon layers 388D). Hydrocarbon layers with less dawsonite (hydrocarbon layers 388C) are provided with less heat by heater 412. Heat output of heater 412 may be tailored by, for example, adjusting the resistance of the heater along the length of the heater. In one embodiment, heater 412 is a temperature limited heater, described herein, that has a higher temperature limit (for example, higher Curie temperature) in sections proximate layers 388D as compared to the temperature limit (Curie temperature) of sections proximate layers 388C. The resistance of heater 412 may also be adjusted by altering the resistive conducting materials along the length of the heater to supply a higher energy input (watts per meter) adjacent to dawsonite rich layers.

[1614] Solution mining dawsonite and nahcolite may be relatively simple processes that produce alumina and soda ash from the formation. In some embodiments, hydrocarbons produced from the formation using the in situ heat treatment process may be fuel for a power plant that produces direct current (DC) electricity at or near the site of the in situ heat treatment process. The produced DC electricity may be used on the site to produce aluminum metal from the alumina using the Hall process. Aluminum metal may be produced from the alumina by melting the alumina in a treatment facility on the site. Generating the DC electricity at the site may save on costs associated with using hydrotreaters, pipelines, or other treatment facilities associated with transporting and/or treating hydrocarbons produced from the formation using the in situ heat treatment process.

[1615] In some embodiments, acid may be introduced into the formation through selected wells to increase the porosity adjacent to the wells. For example, acid may be injected if the formation includes limestone or dolomite. The acid used to treat the selected wells may be acid produced during in situ heat treatment of a section of the formation (for example, hydrochloric acid), or acid produced from byproducts of the in situ heat treatment process (for example, sulfuric acid produced from hydrogen sulfide or sulfur).

[1616] In some embodiments, a saline rich zone is located at or near an unleached portion of the formation. The saline rich zone may be an aquifer in which water has leached out nahcolite and/or other minerals. A high flow rate may pass through the saline rich zone. Saline water from the saline rich zone may be used to solution mine another portion of the formation. In certain

embodiments, a steam and electricity cogeneration facility may be used to heat the saline water prior to use for solution mining.

[1617] FIG. 239 depicts a representation of an embodiment for solution mining with a steam and electricity cogeneration facility. Treatment area 730 may be formed in unleached portion 954 of the formation (for example, an oil shale formation). Several treatment areas 730 may be formed in unleached portion 954 leaving top, side, and/or bottom walls of unleached formation as barriers around the individual treatment areas to inhibit inflow and outflow of formation fluid during the in situ heat treatment process. The thickness of the walls surrounding the treatment areas may be 10 m or more. For example, the side wall near closest to saline zone 966 may be 60 m or more thick, and the top wall may be 30 m or more thick.

[1618] Treatment area 730 may have significant amounts of nahcolite. Saline zone 966 is located at or near treatment area 730. In certain embodiments, zone 966 is located up dip from treatment area 730. Zone 966 may be leached or partially leached such that the zone is mainly filled with saline water.

[1619] In certain embodiments, saline water is removed (pumped) from zone 966 using production well 206. Production well 206 may be located at or near the lowest portion of zone 966 so that saline water flows into the production well. Saline water removed from zone 966 is heated to hot water and/or steam temperatures in facility 968. Facility 968 may burn hydrocarbons to run generators that produce electricity. Facility 968 may burn gaseous and/or liquid hydrocarbons to make electricity. In some embodiments, pulverized coal is used to make electricity. The electricity generated may be used to provide electrical power for heaters or other electrical operations (for example, pumping). Waste heat from the generators is used to make hot water and/or steam from the saline water. After the in situ heat treatment process of one or more treatment areas 730 results in the production of hydrocarbons, at least a portion of the produced hydrocarbons may be used as fuel for facility 968.

[1620] The hot water and/or steam made by facility 968 is provided to solution mining well 944. Solution mining well 944 is used to solution mine treatment area 730. Nahcolite and/or other minerals are removed from treatment area 730 by solution mining well 944. The nahcolite may be removed as a nahcolite solution from treatment area 730. The solution removed from treatment area 730 may be a brine solution with dissolved nahcolite. Heat from the removed nahcolite solution may be used in facility 968 to heat saline water from zone 966 and/or other fluids. The nahcolite solution may then be injected through injection well 602 into zone 966. In some embodiments, injection well 602 injects the nahcolite solution into zone 966 up dip from production well 206. Injection may occur a significant distance up dip so that nahcolite solution may be continuously injected as saline water is removed from the zone without the two fluids

substantially intermixing. In some embodiments, the nahcolite solution from treatment area 730 is provided to injection well 602 without passing through facility 968 (the nahcolite solution bypasses the facility).

[1621] The nahcolite solution injected into zone 966 may be left in the zone permanently or for an extended period of time (for example, after solution mining, production well 206 may be shut in). In some embodiments, the nahcolite stored in zone 966 is accessed at later times. The nahcolite may be produced by removing saline water from zone 966 and processing the saline water to make sodium bicarbonate and/or soda ash.

[1622] Solution mining using saline water from zone 966 and heat from facility 968 to heat the saline water may be a high efficiency process for solution mining treatment area 730. Facility 968 is efficient at providing heat to the saline water. Using the saline water to solution mine decreases costs associated with pumping and/or transporting water to the treatment site. Additionally, solution mining treatment area 730 preheats the treatment area for any subsequent heat treatment of the treatment area, enriches the hydrocarbon content in the treatment area by removing nahcolite, and/or creates more permeability in the treatment area by removing nahcolite.

[1623] In certain embodiments, treatment area 730 is further treated using an in situ heat treatment process following solution mining of the treatment area. A portion of the electricity generated in facility 968 may be used to power heaters for the in situ heat treatment process.

[1624] In some embodiments, a perimeter barrier may be formed around the portion of the formation to be treated. The perimeter barrier may inhibit migration of formation fluid into or out of the treatment area. The perimeter barrier may be a frozen barrier and/or a grout barrier. After formation of the perimeter barrier, the treatment area may be processed to produce desired products.

[1625] Formations that include non-hydrocarbon materials may be treated to remove and/or dissolve a portion of the non-hydrocarbon materials from a section of the formation before hydrocarbons are produced from the section. In some embodiments, the non-hydrocarbon materials are removed by solution mining. Removing a portion of the non-hydrocarbon materials may reduce the carbon dioxide generation sources present in the formation. Removing a portion of the non-hydrocarbon materials may increase the porosity and/or permeability of the section of the formation. Removing a portion of the non-hydrocarbon materials may result in a raised temperature in the section of the formation.

[1626] After solution mining, some of the wells in the treatment may be converted to heater wells, injection wells, and/or production wells. In some embodiments, additional wells are formed in the treatment area. The wells may be heater wells, injection wells, and/or production

wells. Logging techniques may be employed to assess the physical characteristics, including any vertical shifting resulting from the solution mining, and/or the composition of material in the formation. Packing, baffles or other techniques may be used to inhibit formation fluid from entering the heater wells. The heater wells may be activated to heat the formation to a temperature sufficient to support combustion.

[1627] One or more production wells may be positioned in permeable sections of the treatment area. Production wells may be horizontally and/or vertically oriented. For example, production wells may be positioned in areas of the formation that have a permeability of greater than 5 darcy or 10 darcy. In some embodiments, production wells may be positioned near a perimeter barrier. A production well may allow water and production fluids to be removed from the formation. Positioning the production well near a perimeter barrier enhances the flow of fluids from the warmer zones of the formation to the cooler zones.

[1628] FIG. 240 depicts an embodiment of a process for treating a hydrocarbon containing formation with a combustion front. Barrier 958 (for example, a frozen barrier or a grout barrier) may be formed around a perimeter of treatment area 730 of the formation. The footprint defined by the barrier may have any desired shape such as circular, square, rectangular, polygonal, or irregular shape. Barrier 958 may be formed using one or more barrier wells 200. The barrier may be any barrier formed to inhibit the flow of fluid into or out of treatment area 730. In some embodiments, barrier 958 may be a double barrier.

[1629] Heat may be provided to treatment area 730 through heaters positioned in injection wells 602. In some embodiments, the heaters in injection wells 602 heat formation adjacent to the injections wells to temperatures sufficient to support combustion. Heaters in injection wells 602 may raise the formation near the injection wells to temperatures from about 90 °C to about 120 °C or higher (for example, a temperature of about 90 °C, 95 °C, 100 °C, 110 °C, or 120 °C).

[1630] Injection wells 602 may be used to introduce a combustion fuel, an oxidant, steam and/or a heat transfer fluid into treatment area 730, either before, during, or after heat is provided to treatment area 730 from heaters. In some embodiments, injection wells 602 are in communication with each other to allow the introduced fluid to flow from one well to another. Injection wells 602 may be located at positions that are relatively far away from perimeter barrier 958. Introduced fluid may cause combustion of hydrocarbons in treatment area 730. Heat from the combustion may heat treatment area 730 and mobilize fluids toward production wells 206.

[1631] A temperature of treatment area 730 may be monitored using temperature measurement devices placed in monitoring wells and/or temperature measurement devices in injection wells 602, production wells 206, and/or heater wells.

[1632] In some embodiments, a controlled amount of oxidant (for example, air and/or oxygen) is provided in injection wells 602 to advance a heat front towards production wells 206. In some embodiments, the controlled amount of oxidant is introduced into the formation after solution mining has established permeable interconnectivity between at least two injection wells. The amount of oxidant is controlled to limit the advancement rate of the heat front and to limit the temperature of the heat front. The advancing heat front may pyrolyze hydrocarbons. The high permeability in the formation allows the pyrolyzed hydrocarbons to spread in the formation towards production wells without being overtaken by the advancing heat front.

[1633] Vaporized formation fluid and/or gas formed during the combustion process may be removed through gas wells 970 and/or injection wells 602. Venting of gases through gas wells 970 and/or injection wells 602 may force the combustion front in a desired direction.

[1634] In some embodiments, the formation may be heated to a temperature sufficient to cause pyrolysis of the formation fluid by the steam and/or heat transfer fluid. The steam and/or heat transfer fluid may be heated to temperatures of about 300 °C, about 400 °C, about 500 °C, or about 600 °C. In certain embodiments, the steam and/or heat transfer fluid may be co-injected with the fuel and/or oxidant.

[1635] FIG. 241 depicts a cross-sectional representation of an embodiment for treating a hydrocarbon containing formation with a combustion front. As the combustion front is initiated and/or fueled through injection wells 602, formation fluid near periphery 972 of the combustion front becomes mobile and flow towards production wells 206 located proximate barrier 958. Injection wells may include smart well technology. Combustion products and noncondensable formation fluid may be removed from the formation through gas wells 970. In some embodiments, no gas wells are formed in the formation. In such embodiments, formation fluid, combustion products and noncondensable formation fluid are produced through production wells 206. In embodiments that include gas wells 970, condensable formation fluid may be produced through production well 206. In some embodiments, production well 206 is located below injection well 602. Production well 206 may be about 1 m, 5 m, 10 m or more below injection well 602. Production well may be a horizontal well. Periphery 972 of the combustion front may advance from the toe of production well 206 towards the heel of the production well. Production well 206 may include a perforated liner that allows hydrocarbons to flow into the production well. In some embodiments, a catalyst may be placed in production well 206. The catalyst may upgrade and/or stabilize formation fluid in the production well.

[1636] In certain embodiments, a temperature measurement tool assesses the active impedance of an energized heater. The temperature measurement tool may utilize the frequency domain analysis algorithm associated with Partial Discharge measurement technology (PD) coupled with

timed domain reflectometer measurement technology (TDR). A set of frequency domain analysis tools may be applied to a TDR signature. This process may provide unique information in the analysis of the energized heater such as, but not limited to, an impedance log of the entire length of the heater per unit length. The temperature measurement tool may provide certain advantages for assessing the temperature of a downhole heater.

[1637] In certain embodiments, the temperature measurement tool assesses the impedance per unit length and gives a profile on the entire length of the heated section of the heater. The impedance profile may be used in association with laboratory data for the heater (such as temperature and resistance profiles for heaters measured at various loads and frequencies) to assess the temperature per unit length of the heated section. The impedance profile may also be used to assess various computer models for heaters that are used in association with the reservoir simulations.

[1638] In certain embodiments, the temperature measurement tool assesses an accurate impedance profile of a heater in a specific formation after a number of heater wells have been installed and energized in the specific formation. The accurate impedance profile may assess the actual reactive and real power consumption for each heater that is used similarly. This information may be used to properly size surface electrical distribution equipment and/or eliminate any extra capacity designed to accommodate any anticipated heater impedance turndown ratio or any unknown power factor or reactive power consumption for the heaters.

[1639] In certain embodiments, the temperature measurement tool is used to troubleshoot malfunctioning heaters and assess the impedance profile of the length of the heated section. The impedance profile may be able to accurately predict the location of a faulted section and its relative impedance to ground. This information may be used to accurately assess the appropriate reduction in surface voltage to allow the heater to continue to operate in a limited capacity. This method may be more preferable than abandoning the heater in the formation.

[1640] In certain embodiments, frequency domain PD testing offers an improved set of PD characterization tools. A basic set of frequency domain PD testing tools are described in "The Case for Frequency Domain PD Testing In The Context Of Distribution Cable", Steven Boggs, *Electrical Insulation Magazine, IEEE*, Vol. 19, Issue 4, July-Aug. 2003, pages 13-19. Frequency domain PD detection sensitivity under field conditions may be one to two orders of magnitude greater than for time domain testing as a result of there not being a need to trigger on the first PD pulse above the broadband noise, and the filtering effect of the cable between the PD detection site and the terminations. As a result of this greatly increased sensitivity and the set of characterization tools, frequency domain PD testing has been developed into a highly sensitive

and reliable tool for characterizing the condition of distribution cable during normal operation while the cable is energized.

[1641] Subsurface formations (for example, tar sands or heavy hydrocarbon formations) include dielectric media. Dielectric media may exhibit conductivity, relative dielectric constant, and loss tangents at temperatures below 100 °C. Loss of conductivity, relative dielectric constant, and dissipation factor may occur as the formation is heated to temperatures above 100 °C due to the loss of moisture contained in the interstitial spaces in the rock matrix of the formation. To prevent loss of moisture, formations may be heated at temperatures and pressures that minimize vaporization of water. Conductive solutions may be added to the formation to help maintain the electrical properties of the formation.

[1642] Formations may be heated using electrodes to temperatures and pressures that vaporize the water and/or conductive solutions. Material used to produce the current flow, however, may become damaged due to heat stress and/or loss of conductive solutions may limit heat transfer in the layer. In addition, when using electrodes, magnetic fields may form. Due to the presence of magnetic fields, non-ferromagnetic materials may be desired for overburden casings.

[1643] Heat sources with electrically conducting material may allow current flow through a formation from one heat source to another heat source. Current flow between the heat sources with electrically conducting material may heat the formation to increase permeability in the formation and/or lower viscosity of hydrocarbons in the formation. Heating using current flow or "joule heating" through the formation may heat portions of the hydrocarbon layer in a shorter amount of time relative to heating the hydrocarbon layer using conductive heating between heaters spaced apart in the formation.

[1644] In some embodiments, heat sources that include electrically conductive materials are positioned in a hydrocarbon layer. Portions of the hydrocarbon layer may be heated from current generated from the heat sources that flows from the heat sources and through the layer. Positioning of electrically conductive heat sources in a hydrocarbon layer at depths sufficient to minimize loss of conductive solutions may allow hydrocarbons layers to be heated at relatively high temperatures over a period of time with minimal loss of water and/or conductive solutions.

[1645] FIGS. 242-247 depict schematics of embodiments for treating a subsurface formation using heat sources having electrically conductive material. FIG. 242 depicts first conduit 992 and second conduit 994 positioned in wellbores 490, 490' in hydrocarbon layer 388. In certain embodiments, first conduit 992 and/or second conduit 994 are conductors (for example, exposed metal or bare metal conductors). In some embodiments, conduits 992, 994 are oriented substantially horizontally or at an incline in the formation. Conduits 992, 994 may be positioned in or near a bottom portion of hydrocarbon layer 388.

[1646] Wellbores 490, 490' may be open wellbores. In some embodiments, the conduits extend from a portion of the wellbore. In some embodiments, the vertical or overburden portions of wellbores 490, 490' are cemented with non-conductive cement or foam cement. Wellbores 490, 490' may include packers 948 and/or electrical insulators 996. In some embodiments, packers 948 are not necessary. Electrical insulators 996 may insulate conduits 992, 994 from casing 398.

[1647] In some embodiments, the portion of casing 398 adjacent to overburden 400 is made of material that inhibits ferromagnetic effects. The casing in the overburden may be made of fiberglass, polymers, and/or a non-ferromagnetic metal (for example, a high manganese steel). Inhibiting ferromagnetic effects in the portion of casing 398 adjacent to overburden 400 may reduce heat losses to the overburden and/or electrical losses in the overburden. In some embodiments, overburden casings 398 include non-metallic materials such as fiberglass, polyvinylchloride (PVC), chlorinated polyvinylchloride (CPVC), high-density polyethylene (HDPE), and/or non-ferromagnetic metals (for example, non-ferromagnetic high manganese steels). HDPEs with working temperatures in a range for use in overburden 400 include HDPEs available from Dow Chemical Co., Inc. (Midland, Michigan, U.S.A.). In some embodiments, casing 398 includes carbon steel coupled on the inside and/or outside diameter of a non-ferromagnetic metal (for example, carbon steel clad with copper or aluminum) to inhibit ferromagnetic effects or inductive effects in the carbon steel. Other non-ferromagnetic metals include, but are not limited to, manganese steels with at least 15% by weight manganese, 0.7% by weight carbon, 2% by weight chromium, iron aluminum alloys with at least 18% by weight aluminum, and austenitic stainless steels such as 304 stainless steel or 316 stainless steel.

[1648] Portions or all of conduits 992, 994 may include electrically conductive material 998. Electrically conductive materials include, but are not limited to, thick walled copper, heat treated copper ("hardened copper"), carbon steel clad with copper, aluminum, or aluminum or copper clad with stainless steel. Conduits 992, 994 may have dimensions and characteristics that enable the conduits to be used later as injection wells and/or production wells. Conduit 992 and/or conduit 994 may include perforations or openings 1000 to allow fluid to flow into or out of the conduits. In some embodiments, portions of conduit 992 and/or conduit 994 are pre-perforated with coverings initially placed over the perforations and removed later. In some embodiments, conduit 992 and/or conduit 994 include slotted liners.

[1649] After a desired time (for example, after injectivity has been established in the layer), the coverings of the perforations may be removed or slots may be opened to open portions of conduit 992 and/or conduit 994 to convert the conduits to production wells and/or injection wells. In some embodiments, coverings are removed by inserting an expandable mandrel in the conduits to remove coverings and/or open slots. In some embodiments, heat is used to degrade material

placed in the openings in conduit 992 and/or conduit 994. After degradation, fluid may flow into or out of conduit 992 and/or conduit 994.

[1650] Power to electrically conductive material 998 may be supplied from one or more surface power supplies through conductors 1002, 1002'. Conductors 1002, 1002' may be cables supported on a tubular or other support member. In some embodiments, conductors 1002, 1002' are conduits through which electricity flows to conduit 992 or conduit 994. Electrical connectors 1004 may be used to electrically couple conductors 1002, 1002' to conduits 992, 994. Conductor 1002 and conductor 1002' may be coupled to the same power supply to form an electrical circuit. Sections of casing 398 (for example a section between packers 948 and electrical connectors 1004) may include or be made of insulating material (such as enamel coating) to prevent leakage of electrical current towards the surface of the formation.

[1651] In some embodiments, a direct current power source is supplied to either first conduit 992 or second conduit 994. In some embodiments, time varying current is supplied to first conduit 992 and/or second conduit 994. Current flowing from conductors 1002, 1002' to conduits 992, 994 may be low frequency current (for example, about 50 Hz, about 60 Hz, or frequencies up to about 1000 Hz). A voltage differential between the first conduit 992 and second conduit 994 may range from about 100 volts to about 1200 volts, from about 200 volts to about 1000 volts, or from about 500 volts to 700 volts. In some embodiments, higher frequency current and/or higher voltage differentials may be utilized. Use of time varying current may allow longer conduits to be positioned in the formation. Use of longer conduits allows more of the formation to be heated at one time and may decrease overall operating expenses. Current flowing to first conduit 992 may flow through hydrocarbon layer 388 to second conduit 994, and back to the power supply. Flow of current through hydrocarbon layer 388 may cause resistance heating of the hydrocarbon layer.

[1652] During the heating process, current flow in conduits 992, 994 may be measured at the surface. Measuring of the current entering conduits 992, 994 may be used to monitor the progress of the heating process. Current between conduits 992, 994 may increase steadily until a predetermined upper limit (I_{max}) is reached. In some embodiments, vaporization of water occurs at the conduits, at which time a drop in current is observed. Current flow of the system is indicated by arrows 1006. Current flow in hydrocarbon containing layer 388 between conduits 992, 994 heats the hydrocarbon layer between and around the conduits. Conduits 992, 994 may be part of a pattern of conduits in the formation that provide multiple pathways between wells so that a large portion of layer 388 is heated. The pattern may be a regular pattern (for example, a triangular or rectangular pattern) or an irregular pattern.

[1653] FIG. 243 depicts a schematic of an embodiment of a system for treating a subsurface formation using electrically conductive material. Conduit 1008 and ground 1010 may extend from wellbores 490, 490' into hydrocarbon layer 388. Ground 1010 may be a rod or a conduit positioned in hydrocarbon layer 388 between about 5 m and about 30 m away from conduit 1008 (for example, about 10 m, about 15 m, or about 20 m). In some embodiments, electrical insulators 996' electrically isolate ground 1010 from casing 398' and/or conduit section- 1012 positioned in wellbore 490'. As shown, ground 1010 is a conduit that includes openings 1000.

[1654] Conduit 1008 may include sections 1014, 1016 of conductive material 998. Sections 1014, 1016 may be separated by electrically insulating material 1018. Electrically insulating material 1018 may include polymers and/or one or more ceramic isolators. Section 1014 may be electrically coupled to the power supply by conductor 1002. Section 1016 may be electrically coupled to the power supply by conductor 1002'. Electrical insulators 996 may separate conductor 1002 from conductor 1002'. Electrically insulating material 1018 may have dimensions and insulating properties sufficient to inhibit current from section 1014 flowing across insulation material 1018 to section 1016. For example, a length of electrically insulating material 1018 may be about 30 meters, about 35 meters, about 40 meters, or greater. Using a conduit that has electrically conductive sections 1014, 1016 may allow fewer wellbores to be drilled in the formation. Conduits having electrically conductive sections ("segmented heat sources") may allow longer conduit lengths. In some embodiments, segmented heat sources allow injection wells used for drive processes (for example, steam assisted gravity drainage and/or cyclic steam drive processes) to be spaced further apart, and thus achieve an overall higher recovery efficiency.

[1655] Current provided through conductor 1002 may flow to conductive section 1014 through hydrocarbon layer 388 to a section of ground 1010 opposite section 1014. The electrical current may flow along ground 1010 to a section of the ground opposite section 1016. The current may flow through hydrocarbon layer 388 to section 1016 and through conductor 1002' back to the power circuit to complete the electrical circuit. Electrical connector 1020 may electrically couple section 1016 to conductor 1002'. Current flow is indicated by arrows 1006. Current flow through hydrocarbon layer 388 may heat the hydrocarbon layer to create fluid injectivity in the layer, mobilize hydrocarbons in the layer, and/or pyrolyze hydrocarbons in the layer. When using segmented heat sources, the amount of current required for the initial heating of the hydrocarbon layer may be at least 50% less than current required for heating using two non-segmented heat sources or two electrodes. Hydrocarbons may be produced from hydrocarbon layer 388 and/or other sections of the formation using production wells. In some embodiments, one or more portions of conduit 1008 is positioned in a shale layer and ground 1010 is positioned

in hydrocarbon layer 388. Current flow through conductors 1002, 1002' in opposite directions may allow for cancellation of at least a portion of the magnetic fields due to the current flow. Cancellation of at least a portion of the magnetic fields may inhibit induction effects in the overburden portion of conduit 1008 and the wellhead of wellbore 490.

[1656] FIG. 244 depicts an embodiment in which first conduit 1008 and second conduit 1008' are used for heating hydrocarbon layer 388. Electrically insulating material 1018 may separate sections 1014, 1016 of first conduit 1008. Electrically insulating material 1018' may separate sections 1014', 1016' of second conduit 1008'.

[1657] Current may flow from a power source through conductor 1002 of first conduit 1008 to section 1014. The current may flow through hydrocarbon containing layer 388 to section 1016' of second conduit 1008'. The current may return to the power source through conductor 1002' of second conduit 1008'. Similarly, current may flow through conductor 1002 of second conduit 1008' to section 1014', through hydrocarbon layer 388 to section 1016 of first conduit 1008, and the current may return to the power source through conductor 1002' of the first conduit 1008. Current flow is indicated by arrows 1006. Generation of current flow from electrically conductive sections of conduits 1008, 1008' may heat portions of hydrocarbon layer 388 between the conduits and create fluid injectivity in the layer, mobilize hydrocarbons in the layer, and/or pyrolyze hydrocarbons in the layer. In some embodiments, one or more portions of conduits 1008, 1008' are positioned in shale layers.

[1658] By creating opposite current flow through the wellbores, as described with reference to FIGS. 243 and 244, magnetic fields in the overburden may cancel out. Cancellation of the magnetic fields in the overburden may allow ferromagnetic materials to be used in overburden casings 398. Using ferromagnetic casings in the wellbores may be less expensive and/or easier to install than non-ferromagnetic casings (such as fiberglass casings).

[1659] In some embodiments, two or more conduits may branch from a common wellbore. FIG. 245 depicts a schematic of an embodiment of two conduits extending from one common wellbore. Extending the conduits from one common wellbore may reduce costs by forming fewer wellbores in the formation. Using common wellbores may allow wellbores to be spaced further apart and produce the same heating efficiencies and the same heating times as drilling two different wellbores for each conduit through the formation. Using common wellbores may allow ferromagnetic materials to be used in overburden casing 398 since the magnetic fields cancel due to the approximately equal and opposite flow of current in the overburden section of conduits 992, 994. Extending conduits from one common wellbore may allow longer conduits to be used.

[1660] Conduits 992, 994 may extend from common vertical portion 1022 of wellbore 490. Conduit 994 may be installed through an opening (for example, a milled window) in vertical

portion 1022. Conduits 992, 994 may extend substantially horizontally or inclined from vertical portion 1022. Conduits 992, 994 may include electrically conductive material 998. In some embodiments, conduits 992, 994 include electrically conductive sections and electrically insulating material, as described for conduit 1008 in FIGS. 243 and 244. Conduit 992 and/or conduit 994 may include openings 1000. Current may flow from a power source to conduit 992 through conductor 1002. The current may pass through hydrocarbon containing layer 388 to conduit 994. The current may pass from conduit 994 through conductor 1002' back to the power source to complete the circuit. The flow of current as shown by arrows 1006 through hydrocarbon layer 388 from conduits 992, 994 heats the hydrocarbon layer between the conduits.

[1661] In certain embodiments, electrodes (such as conduits 992, 994, conduit 1008, and/or ground 1010) are coated or cladded with high electrical conductivity material to reduce energy losses. In some embodiments, overburden conductors (such as conductor 1002) are coated or cladded with high electrical conductivity material. FIG. 246 depicts an embodiment of conduit 992 with heating zone cladding 1396 and conductor 1002 with overburden cladding 1398. In certain embodiments, conduit 992 is made of carbon steel. Cladding 1396 may be copper or another highly electrically conductive material. In certain embodiments, cladding 1396 and/or cladding 1398 is coupled to conduit 992 and/or conductor 1002 by wrapping thin layers of the cladding onto the conduit or conductor. In some embodiments, cladding 1396 and/or cladding 1398 is coupled to conduit 992 and/or conductor 1002 by depositing or coating the cladding using electrolysis.

[1662] In certain embodiments, overburden cladding 1398 has a substantially constant thickness along the length of conductor 1002 as the current along the conductor is substantially constant. In the hydrocarbon layer of the formation, however, electrical current flows into the formation and electrical current decreases linearly along the length of conduit 992 if current injection into the formation is uniform. Since current in conduit 992 decreases along the length of the conduit, heating zone cladding 1396 can decrease in thickness linearly along with the current while still reducing energy losses to acceptable levels along the length of the conduit. Having heating zone cladding 1396 taper to a thinner thickness along the length of conduit 992 reduces the total cost of putting the cladding on the conduit.

[1663] The taper of heating zone cladding 1396 may be selected to provide certain electrical output characteristics along the length of conduit 992. In certain embodiments, the taper of heating zone cladding 1396 is designed to provide an approximately constant current density along the length of the conduit such that the current decreases linearly along the length of the conduit. In some embodiments, the thickness and taper of heating zone cladding 1396 is

designed such that the formation is heated at or below a selected heating rate (for example, at or below about 160 W/m). In some embodiments, the thickness and taper of heating zone cladding 1396 is designed such that a voltage gradient along the cladding is less than a selected value (for example, less than about 0.3 V/m).

[1664] In certain embodiments, analytical calculations may be made to optimize the thickness and taper of heating zone cladding 1396. The thickness and taper of heating zone cladding 1396 may be optimized to produce substantial cost savings over using a heating zone cladding of constant thickness. For example, it may be possible reduce costs by more than 50% by tapering heating zone cladding 1396 along the length of conduit 992.

[1665] In certain embodiments, boreholes of electrodes (such as conduits 992, 994, conduit 1008, and/or ground 1010) are filled with an electrically conductive material and/or a thermally conductive material. For example, the insides of conduits may be filled with the electrically conductive material and/or the thermally conductive material. In certain embodiments, the wellbores with electrodes are filled with graphite, conductive cement, or combinations thereof. Filling the wellbore with electrically and/or thermally conductive material may increase the effective electrical diameter of the electrode for conducting current into the formation and/or increase distribution of any heat generated in the wellbore.

[1666] In some embodiments, a subsurface formation is heated using heating systems described in the embodiments depicted in FIGS. 242, 243, 244, and/or 245 to heat fluids in hydrocarbon layer 388 to mobilization, visbreaking, and/or pyrolyzation temperatures. Such heated fluids may be produced from the hydrocarbon layer and/or from other sections of the formation. As the hydrocarbon layer 388 is heated, the conductivity of the heated portion of the hydrocarbon layer increases. For example, conductivity of hydrocarbon layers close to the surface may increase by as much as a factor of three when the temperature of the formation increases from 20 °C to 100 °C. For deeper layers, where the water vaporization temperature is higher due to increased fluid pressure, the increase in conductivity may be greater. Greater increases in conductivity may increase the heating rate of the formation. Thus, as the conductivity increases in the formation, increases in heating may be more concentrated in deeper layers.

[1667] As a result of heating, the viscosity of heavy hydrocarbons in a hydrocarbon layer is reduced. Reducing the viscosity may create more injectivity in the layer and/or mobilize hydrocarbons in the layer. As a result of being able to rapidly heat the hydrocarbon layer using heating systems described in the embodiments depicted in FIGS. 242, 243, 244, and/or 245, sufficient fluid injectivity in the hydrocarbon layer may be achieved more quickly, for example, in about two years. In some embodiments, these heating systems are used to create drainage

paths between the heat sources and production wells for a drive and/or a mobilization process. In some embodiments, these heating systems are used to provide heat during the drive process. The amount of heat provided by the heating systems may be small compared to the heat input from the drive process (for example, the heat input from steam injection).

[1668] Once sufficient fluid injectivity has been established, a drive fluid, a pressuring fluid, and/or a solvation fluid may be injected in the heated portion of hydrocarbon layer 388. In some embodiments (for example, the embodiments depicted in FIGS. 242 and 245), conduit 994 is perforated and fluid is injected through the conduit to mobilize and/or further heat hydrocarbon layer 388. Fluids may drain and/or be mobilized towards conduit 992. Conduit 992 may be perforated at the same time as conduit 994 or perforated at the start of production. Formation fluids may be produced through conduit 992 and/or other sections of the formation.

[1669] As shown in FIG. 247, conduit 992 is positioned in layer 1024 located between hydrocarbon layers 388A and 388B. Conduit 994 is positioned in hydrocarbon layer 388A. Conduits 992, 994, shown in FIG. 247, may be any of conduits 992, 994, depicted in FIGS. 242 and/or 245, as well as conduits 1008, 1008' or ground 1010, depicted in FIGS. 243 and 244. In some embodiments, portions of conduit 992 are positioned in hydrocarbon layers 388A or 388B and in layer 1024.

[1670] Layer 1024 may be a conductive layer, water/sand layer, or hydrocarbon layer that has different porosity than hydrocarbon layer 388A and/or hydrocarbon layer 388B. In some embodiments, layer 1024 is a shale layer. Layer 1024 may have conductivities ranging from about 0.2 mho/m to about 0.5 mho/m. Hydrocarbon layers 388A and/or 388B may have conductivities ranging from about 0.02 mho/m to about 0.05 mho/m. Conductivity ratios between layer 1024 and hydrocarbon layers 388A and/or 388B may range from about 10:1, about 20:1, or about 100:1. When layer 1024 is a shale layer, heating the layer may desiccate the shale layer and increase the permeability of the shale layer to allow fluid to flow through the shale layer. The increased permeability in the shale layer allows mobilized hydrocarbons to flow from hydrocarbon layer 388A to hydrocarbon layer 388B, allows drive fluids to be injected in hydrocarbon layer 388A, and/or allows steam drive processes (for example, SAGD, cyclic steam soak (CSS), sequential CSS and SAGD or steam flood, or simultaneous SAGD and CSS) to be performed in hydrocarbon layer 388A.

[1671] In some embodiments, a conductive layer is selected to provide lateral continuity of conductivity within the conductive layer and to provide a substantially higher conductivity, for a given thickness, than the surrounding hydrocarbon layers. Thin conductive layers selected on this basis may substantially confine the heat generation within and around the conductive layers and allow much greater spacing between rows of electrodes. In some embodiments, layers to be

heated are selected, on the basis of resistivity well logs, to provide lateral continuity of conductivity. Selection of layers to be heated is described in U.S. Patent No. 4,926,941 to Glandt et al., which is incorporated herein by reference.

[1672] Once sufficient fluid injectivity is created, fluid may be injected in layer 1024 through an injection well and/or conduit 992 to heat or mobilize fluids in hydrocarbon layer 388B. Fluids may be produced from hydrocarbon layer 388B and/or other sections of the formation. In some embodiments, fluid is injected in conduit 994 to mobilize and/or heat in hydrocarbon layer 388A. Heated and/or mobilized fluids may be produced from conduit 992 and/or other production wells located in hydrocarbon layer 388B and/or other sections of the formation.

[1673] In certain embodiments, a solvation fluid, in combination with a pressurizing fluid, is used to treat the hydrocarbon formation in addition to the in situ heat treatment process. In some embodiments, the solvation fluid, in combination with the pressurizing fluid, is used after the hydrocarbon formation has been treated using a drive process. In some embodiments, solvation fluids are foamed or made into foams to improve the efficiency of the drive process. Since an effective viscosity of the foam may be greater than the viscosity of the individual components, the use of a foaming composition may improve the sweep efficiency of the drive fluid.

[1674] In some embodiments, the solvation fluid includes a foaming composition. The foaming composition may be injected simultaneously or alternately with the pressurizing fluid and/or the drive fluid to form foam in the heated section. Use of foaming compositions may be more advantageous than use of polymer solutions since foaming compositions are thermally stable at temperatures up to 600 °C while polymer compositions may degrade at temperatures above 150 °C. Use of foaming compositions at temperatures above about 150 °C may allow more hydrocarbon fluids and/or more efficient removal of hydrocarbons from the formation as compared to use of polymer compositions.

[1675] Foaming compositions may include, but are not limited to, surfactants. In certain embodiments, the foaming composition includes a polymer, a surfactant, an inorganic base, water, steam, and/or brine. The inorganic base may include, but is not limited to, sodium hydroxide, potassium hydroxide, potassium carbonate, potassium bicarbonate, sodium carbonate, sodium bicarbonate, or mixtures thereof. Polymers include polymers soluble in water or brine such as, but not limited to, ethylene oxide or propylene oxide polymers.

[1676] Surfactants include ionic surfactants and/or nonionic surfactants. Examples of ionic surfactants include alpha-olefinic sulfonates, alkyl sodium sulfonates, and sodium alkyl benzene sulfonates. Non-ionic surfactants include, for example, triethanolamine. Surfactants capable of forming foams include, but are not limited to, alpha-olefinic sulfonates, alkylpolyalkoxyalkylene sulfonates, aromatic sulfonates, alkyl aromatic sulfonates, alcohol ethoxy glycerol sulfonates

(AEGS), or mixtures thereof. Non-limiting examples of surfactants capable of being foamed include AEGS 25-12 surfactant, sodium dodecyl 3EO sulfate, and sulfates made from branched alcohols made using the Guerbet method such as, for example, sodium dodecyl (Guerbert) 3PO sulfate[63], ammonium isotridecyl(Guerbert) 4PO sulfate[63], sodium tetradecyl (Guerbert) 4PO sulfate[63]. Nonionic and ionic surfactants and/or methods of use and/or methods of foaming for treating a hydrocarbon formation are described in U.S. Patent Nos. 4,643,256 to Dilgren et al.; 5,193,618 to Loh et al.; 5,046,560 to Teletzke et al.; 5,358,045 to Sevigny et al.; 6,439,308 to Wang; 7,055,602 to Shpakoff et al.; 7,137,447 to Shpakoff et al.; 7,229,950 to Shpakoff et al.; and 7,262,153 to Shpakoff et al.; and by Wellington et al., in "Surfactant-Induced Mobility Control for Carbon Dioxide Studied with Computerized Tomography," American Chemical Society Symposium Series No. 373, 1988.

[1677] Foam may be formed in the formation by injecting the foaming composition during or after addition of steam. Pressurizing fluid (for example, carbon dioxide, methane, and/or nitrogen) may be injected in the formation before, during, or after the foaming composition is injected. A type of pressurizing fluid may be based on the surfactant used in the foaming composition. For example, carbon dioxide may be used with alcohol ethoxy glycerol sulfonates. The pressurizing fluid and foaming composition may mix in the formation and produce foam. In some embodiments, non-condensable gas is mixed with the foaming composition prior to injection to form a pre-foamed composition. The foaming composition, the pressurizing fluid, and/or the pre-foamed composition may be periodically injected in the heated formation. The foaming composition, pre-foamed compositions, drive fluids, and/or pressurizing fluids may be injected at a pressure sufficient to displace the formation fluids without fracturing the reservoir.

[1678] In some embodiments, electrodes may be positioned in wellbores to heat hydrocarbon layers in a subsurface formation. Electrodes may be positioned vertically in the hydrocarbon formation or oriented substantially horizontal or inclined. Heating hydrocarbon formations with electrodes is described in U.S. Patent No. 4,084,637 to Todd; 4,926,941 to Glandt et al.; and 5,046,559 to Glandt, all of which are incorporate herein by reference in their entirety. Electrodes used for heating hydrocarbon formations may have bare elements at the ends of the electrodes. Heating of the hydrocarbon layers may subject the bare element ends to increased current because of the near and far field voltage fields concentrating on the ends. Coating of the electrode to form high voltage stress cones ("stress grading") around sections of the electrode or the entire electrode may enhance the performance of the electrode. FIG. 248A depicts a schematic of an embodiment of an electrode with a sleeve over a section of the electrode. FIG. 248B depicts a schematic of an embodiment of an uncoated electrode. FIG. 249A depicts a schematic of another embodiment of a coated electrode. FIG. 249B depicts a schematic of

another embodiment of an uncoated electrode. Electrode 1020 may include a coating that forms sleeve 1026 around an end (as shown in FIG. 248A) or substantially all (as shown in FIG. 249A) of the electrode. Sleeve 1026 may be formed from a positive temperature coefficient polymer and/or a heat shrinkable material. When sleeve 1026 is coated, as shown by arrows in FIGS. 248A and 249A, current flow is distributed outwardly along sleeve 1026 when electrode 1020 is energized rather than the ends or portions of the electrode, as shown in FIGS. 248B and 249B.

[1679] In some embodiments, bulk resistance along sections of the electrode may be increased by layering conductive materials and insulating layers along a section of the electrode. Examples of such electrodes are electrodes made by Raychem® (Tyco International Inc., Princeton, New Jersey, U.S.A.). Increased bulk resistance may allow voltage along the sleeve of the electrode to be distributed, thus decreasing the current density at the end of the electrode.

[1680] FIG. 250 depicts an embodiment of a u-shaped heater that has an inductively energized tubular. Heater 412 includes electrical conductor 408 and tubular 578 in an opening that spans between wellbore 490A and wellbore 490B. In certain embodiments, electrical conductor 408 and/or the current carrying portion of the electrical conductor is electrically insulated from tubular 578. Electrical conductor 408 and/or the current carrying portion of the electrical conductor is electrically insulated from tubular 578 such that electrical current does not flow from the electrical conductor to the tubular, or vice versa (for example, the tubular is not electrically connected to the electrical conductor).

[1681] In some embodiments, electrical conductor 408 is centralized inside tubular 578 (for example, using centralizers 390 or other support structures, as shown in FIG. 251). Centralizers 390 may electrically insulate electrical conductor 408 from tubular 578. In some embodiments, tubular 578 contacts electrical conductor 408. For example, tubular 578 may hang, drape, or otherwise touch electrical conductor 408. In some embodiments, electrical conductor 408 includes electrical insulation (for example, magnesium oxide or porcelain enamel) that insulates the current carrying portion of the electrical conductor from tubular 578. The electrical insulation inhibits current from flowing between the current carrying portion of electrical conductor 408 and tubular 578 if the electrical conductor and the tubular are in physical contact with each other.

[1682] In some embodiments, electrical conductor 408 is an exposed metal conductor heater or a conductor-in-conduit heater. In certain embodiments, electrical conductor 408 is an insulated conductor such as a mineral insulated conductor. The insulated conductor may have a copper core, copper alloy core, or a similar electrically conductive, low resistance core that has low electrical losses. In some embodiments, the core is a copper core with a diameter between about 0.5" (1.27 cm) and about 1" (2.54 cm). The sheath or jacket of the insulated conductor may be a

non-ferromagnetic, corrosion resistant steel such as 347 stainless steel, 625 stainless steel, 825 stainless steel, 304 stainless steel, or copper with a protective layer (for example, a protective cladding). The sheath may have an outer diameter of between about 1" (2.54 cm) and about 1.25" (3.18 cm).

[1683] In some embodiments, the sheath or jacket of the insulated conductor is in physical contact with the tubular 578 (for example, the tubular is in physical contact with the sheath along the length of the tubular) or the sheath is electrically connected to the tubular. In such embodiments, the electrical insulation of the insulated conductor electrically insulates the core of the insulated conductor from the jacket and the tubular. FIG. 252 depicts an embodiment of an induction heater with the sheath of an insulated conductor in electrical contact with tubular 578. Electrical conductor 408 is the insulated conductor. The sheath of the insulated conductor is electrically connected to tubular 578 using electrical contactors 1400. In some embodiments, electrical contactors 1400 are sliding contactors. In certain embodiments, electrical contactors 1400 electrically connect the sheath of the insulated conductor to tubular 578 at or near the ends of the tubular. Electrically connecting at or near the ends of tubular 578 substantially equalizes the voltage along the tubular with the voltage along the sheath of the insulated conductor. Equalizing the voltages along tubular 578 and along the sheath may inhibit arcing between the tubular and the sheath.

[1684] Tubular 578, shown in FIGS. 250, 251, and 252, may be ferromagnetic or include ferromagnetic materials. Tubular 578 may have a thickness such that when electrical conductor 408 is energized with time-varying current, the electrical conductor induces electrical current flow on the surfaces of tubular 578 due to the ferromagnetic properties of the tubular (for example, current flow is induced on both the inside of the tubular and the outside of the tubular). Current flow is induced in the skin depth of the surfaces of tubular 578 so that the tubular operates as a skin effect heater. In certain embodiments, the induced current circulates axially (longitudinally) on the inside and/or outside surfaces of tubular 578. Longitudinal flow of current through electrical conductor 408 induces primarily longitudinal current flow in tubular 578 (the majority of the induced current flow is in the longitudinal direction in the tubular). Having primarily longitudinal induced current flow in tubular 578 may provide a higher resistance per foot than if the induced current flow is primarily angular current flow.

[1685] In certain embodiments, current flow in tubular 578 is induced with low frequency current in electrical conductor 408 (for example, from 50 Hz or 60 Hz up to about 1000 Hz). In some embodiments, induced currents on the inside and outside surfaces of tubular 578 are substantially equal.

[1686] In certain embodiments, tubular 578 has a thickness that is greater than the skin depth of the ferromagnetic material in the tubular at or near the Curie temperature of the ferromagnetic material or at or near the phase transformation temperature of the ferromagnetic material. For example, tubular 578 may have a thickness of at least 2.1, at least 2.5 times, at least 3 times, or at least 4 times the skin depth of the ferromagnetic material in the tubular near the Curie temperature or the phase transformation temperature of the ferromagnetic material. In certain embodiments, tubular 578 has a thickness of at least 2.1 times, at least 2.5 times, at least 3 times, or at least 4 times the skin depth of the ferromagnetic material in the tubular at about 50 °C below the Curie temperature or the phase transformation temperature of the ferromagnetic material.

[1687] In certain embodiments, tubular 578 is carbon steel. In some embodiments, tubular 578 is coated with a corrosion resistant coating (for example, porcelain or ceramic coating) and/or an electrically insulating coating. In some embodiments, electrical conductor 408 has an electrically insulating coating. Examples of the electrically insulating coating on tubular 578 and/or electrical conductor 408 include, but are not limited to, a porcelain enamel coating, alumina coating, or alumina-titania coating. In some embodiments, tubular 578 and/or electrical conductor 408 are coated with a coating such as polyethylene or another suitable low friction coefficient coating that may melt or decompose when the heater is energized. The coating may facilitate placement of the tubular and/or the electrical conductor in the formation.

[1688] In some embodiments, tubular 578 includes corrosion resistant ferromagnetic material such as, but not limited to, 410 stainless steel, 446 stainless steel, T/P91 stainless steel, T/P92 stainless steel, alloy 52, alloy 42, and Invar 36. In some embodiments, tubular 578 is a stainless steel tubular with cobalt added (for example, between about 3% by weight and about 10% by weight cobalt added) and/or molybdenum (for example, about 0.5 % molybdenum by weight).

[1689] At or near the Curie temperature or the phase transformation temperature of the ferromagnetic material in tubular 578, the magnetic permeability of the ferromagnetic material decreases rapidly. When the magnetic permeability of tubular 578 decreases at or near the Curie temperature or the phase transformation temperature, there is little or no current flow in the tubular because, at these temperatures, the tubular is essentially non-ferromagnetic and electrical conductor 408 is unable to induce current flow in the tubular. With little or no current flow in tubular 578, the temperature of the tubular will drop to lower temperatures until the magnetic permeability increases and the tubular becomes ferromagnetic. Thus, tubular 578 self-limits at or near the Curie temperature or the phase transformation temperature and operates as a temperature limited heater due to the ferromagnetic properties of the ferromagnetic material in the tubular. Because current is induced in tubular 578, the turndown ratio may be higher and the drop in

current sharper for the tubular than for temperature limited heaters that apply current directly to the ferromagnetic material. For example, heaters with current induced in tubular 578 may have turndown ratios of at least about 5, at least about 10, or at least about 20 while temperature limited heaters that apply current directly to the ferromagnetic material may have turndown ratios that are at most about 5.

[1690] When current is induced in tubular 578, the tubular provides heat to hydrocarbon layer 388 and defines the heating zone in the hydrocarbon layer. In certain embodiments, tubular 578 heats to temperatures of at least about 300 °C, at least about 500 °C, or at least about 700 °C. Because current is induced on both the inside and outside surfaces of tubular 578, the heat generation of the tubular is increased as compared to temperature limited heaters that have current directly applied to the ferromagnetic material and current flow is limited to one surface. Thus, less current may be provided to electrical conductor 408 to generate the same heat as heaters that apply current directly to the ferromagnetic material. Using less current in electrical conductor 408 decreases power consumption and reduces power losses in the overburden of the formation.

[1691] In certain embodiments, tubulars 578 have large diameters. The large diameters may be used to equalize or substantially equalize high pressures on the tubular from either the inside or the outside of the tubular. In some embodiments, tubular 578 has a diameter in a range between about 1.5" (about 3.8 cm) and about 5" (about 12.7 cm). In some embodiments, tubular 578 has a diameter in a range between about 3 cm and about 13 cm, between about 4 cm and about 12 cm, or between about 5 cm and about 11 cm. Increasing the diameter of tubular 578 may provide more heat output to the formation by increasing the heat transfer surface area of the tubular.

[1692] In some embodiments, fluids flow through the annulus of tubular 578 or through another conduit inside the tubular. The fluids may be used, for example, to cool down the heater, to recover heat from the heater, and/or to initially heat the formation before energizing the heater.

[1693] In some embodiments, a method for heating a hydrocarbon containing formation may include providing a time-varying electrical current at a first frequency to an elongated electrical conductor located in the formation using an inductive heater. Electrical current flow may be induced in a ferromagnetic conductor with the time-varying electrical current at the first frequency. In some embodiments, the ferromagnetic conductor may at least partially surround and at least partially extend lengthwise around the electrical conductor. The ferromagnetic conductor may be resistively heated with the induced electrical current flow. For example, the ferromagnetic conductor may be resistively heated with the induced electrical current flow such that the ferromagnetic conductor resistively heats up to a first temperature. The first temperature may be at most about 300 °C. Heat may be allowed to transfer from the ferromagnetic conductor

at the first temperature to at least a part of the formation. At least some water in the formation may be vaporized with the ferromagnetic conductor at the first temperature. At these lower temperatures (for example, up to about 260 °C or about 300 °C) coke may be inhibited from forming without inducing heater damage.

[1694] In some embodiments, the time-varying electrical current may be provided at a second frequency to the elongated electrical conductor. Electrical current flow may be induced in the ferromagnetic conductor with the time-varying electrical current at the second frequency. The ferromagnetic conductor may be resistively heated with the induced electrical current flow. For example, the ferromagnetic conductor may be resistively heated with the induced electrical current flow such that the ferromagnetic conductor resistively heats up to a second temperature. The second temperature may be above about 300 °C. Heat may be allowed to transfer from the ferromagnetic conductor at the second temperature to at least a part of the formation. At least some hydrocarbons in the part of the formation may be mobilized with the ferromagnetic conductor at the second temperature. Caution must be taken with the second frequency, in that it must not be raised too high or the inductive heater may be damaged. In some embodiments, a multiple frequency low temperature inductive heater may be provided by Siemens AG (Munich, Germany).

[1695] Many different types of wells or wellbores may be used to treat the hydrocarbon containing formation using the in situ heat treatment process. In some embodiments, vertical and/or substantially vertical wells are used to treat the formation. In some embodiments, horizontal (such as J-shaped wells and/or L-shaped wells), and/or u-shaped wells are used to treat the formation. In some embodiments, combinations of horizontal wells, vertical wells, and/or other combinations are used to treat the formation. In certain embodiments, wells extend through the overburden of the formation to a hydrocarbon containing layer of the formation. Heat in the wells may be lost to the overburden. In certain embodiments, surface and/or overburden infrastructures used to support heaters and/or production equipment in horizontal wellbores and/or u-shaped wellbores are large in size and/or numerous.

[1696] In certain embodiments, heaters, heater power sources, production equipment, supply lines, and/or other heater or production support equipment are positioned in tunnels to enable smaller sized heaters and/or smaller sized equipment to be used to treat the formation. Positioning such equipment and/or structures in tunnels may also reduce energy costs for treating the formation, reduce emissions from the treatment process, facilitate heating system installation, and/or reduce heat loss to the overburden as compared to hydrocarbon recovery processes that utilize surface based equipment. The tunnels may be, for example, substantially horizontal tunnels and/or inclined tunnels. U.S. Published Patent Application Nos. 2007/0044957 to

Watson et al.; 2008/0017416 to Watson et al.; and 2008/0078552 to Donnelly et al. describe methods of drilling from a shaft for underground recovery of hydrocarbons and methods of underground recovery of hydrocarbons.

[1697] In certain embodiments, tunnels and/or shafts are used in combination with wells to treat the hydrocarbon containing formation using the in situ heat treatment process. FIG. 253 depicts a perspective view of underground treatment system 1028. Underground treatment system 1028 may be used to treat hydrocarbon layer 388 using the in situ heat treatment process. In certain embodiments, underground treatment system 1028 includes shafts 1030, utility shafts 1032, tunnels 1034A, tunnels 1034B, and wellbores 490. Tunnels 1034A, 1034B may be located in overburden 400, an underburden, a non-hydrocarbon containing layer, or a low hydrocarbon content layer of the formation. In some embodiments, tunnels 1034A, 1034B are located in a rock layer of the formation. In some embodiments, tunnels 1034A, 1034B are located in an impermeable portion of the formation. For example, tunnels 1034A, 1034B may be located in a portion of the formation having a permeability of at most about 1 millidarcy.

[1698] Shafts 1030 and/or utility shafts 1032 may be formed and strengthened (for example, supported to inhibit collapse) using methods known in the art. For example, shafts 1030 and/or utility shafts 1032 may be formed using blind and raised bore drilling technologies using mud weight and lining to support the shafts. Conventional techniques may be used to raise and lower equipment in the shafts and/or to provide utilities through the shafts.

[1699] Tunnels 1034A, 1034B may be formed and strengthened (for example, supported to inhibit collapse) using methods known in the art. For example, tunnels 1034A, 1034B may be formed using road-headers, drill and blast, tunnel boring machine, and/or continuous miner technologies to form the tunnels. Tunnel strengthening may be provided by, for example, roof support, mesh, and/or shot-crete. Tunnel strengthening may inhibit tunnel collapse and/or to inhibit movement of the tunnels during heat treatment of the formation.

[1700] In certain embodiments, the status of tunnels 1034A, tunnels 1034B, shafts 1030, and/or utility shafts 1032 are monitored for changes in structure or integrity of the tunnels or shafts. For example, conventional mine survey technologies may be used to continuously monitor the structure and integrity of the tunnels and/or shafts. In addition, systems may be used to monitor changes in characteristics of the formation that may affect the structure and/or integrity of the tunnels or shafts.

[1701] In certain embodiments, tunnels 1034A, 1034B are substantially horizontal or inclined in the formation. In some embodiments, tunnels 1034A extend along the line of shafts 1030 and utility shafts 1032. Tunnels 1034B may connect between tunnels 1034A. In some embodiments,

tunnels 1034B allow cross-access between tunnels 1034A. In some embodiments, tunnels 1034B are used to cross-connect production between tunnels 1034A below the surface of the formation.

[1702] Tunnels 1034A, 1034B may have cross-section shapes that are rectangular, circular, elliptical, horseshoe-shaped, irregular-shaped, or combinations thereof. Tunnels 1034A, 1034B may have cross-sections large enough for personnel, equipment, and/or vehicles to pass through the tunnels. In some embodiments, tunnels 1034A, 1034B have cross-sections large enough to allow personnel and/or vehicles to freely pass by equipment located in the tunnels. In some embodiments, the tunnels described in embodiments herein have an average diameter of at least 1 m, at least 2 m, at least 5 m, or at least 10 m.

[1703] In certain embodiments, shafts 1030 and/or utility shafts 1032 connect with tunnels 1034A in overburden 400. In some embodiments, shafts 1030 and/or utility shafts 1032 connect with tunnels 1034A in another layer of the formation. Shafts 1030 and/or utility shafts 1032 may be sunk or formed using methods known in the art for drilling and/or sinking mine shafts. In certain embodiments, shafts 1030 and/or utility shafts 1032 connect with tunnels 1034A in overburden 400 and/or hydrocarbon layer 388 to surface 404. In some embodiments, shafts 1030 and/or utility shafts 1032 extend into hydrocarbon layer 388. For example, shafts 1030 may include production conduits and/or other production equipment to produce fluids from hydrocarbon layer 388 to surface 404.

[1704] In certain embodiments, shafts 1030 and/or utility shafts 1032 are substantially vertical or slightly angled from vertical. In certain embodiments, shafts 1030 and/or utility shafts 1032 have cross-sections large enough for personnel, equipment, and/or vehicles to pass through the shafts. In some embodiments, shafts 1030 and/or utility shafts 1032 have circular cross-sections. Shafts 1030 and/or utility shafts 1032 may have an average cross-sectional diameter of at least 0.5 m, at least 1 m, at least 2 m, at least 5 m, or at least 10 m.

[1705] In certain embodiments, the distance between two shafts 1030 is between 500 m and 5000 m, between 1000 m and 4000 m, or between 2000 m and 3000 m. In certain embodiments, the distance between two utility shafts 1032 is between 100 m and 1000 m, between 250 m and 750 m, or between 400 m and 600 m.

[1706] In certain embodiments, shafts 1030 are larger in cross-section than utility shafts 1032. Shafts 1030 may allow access to tunnels 1034A for large ventilation, materials, equipment, vehicles, and personnel. Utility shafts 1032 may provide service corridor access to tunnels 1034A for equipment or structures such as, but not limited to, power supply legs, production risers, and/or ventilation openings. In some embodiments, shafts 1030 and/or utility shafts 1032 include monitoring and/or sealing systems to monitor and assess gas levels in the shafts and to seal off the shafts if needed.

[1707] FIG. 254 depicts an exploded perspective view of a portion of underground treatment system 1028 and tunnels 1034A. In certain embodiments, tunnels 1034A include heater tunnels 1036 and/or utility tunnels 1038. In some embodiments, tunnels 1034A include additional tunnels such as access tunnels and/or service tunnels. FIG. 255 depicts an exploded perspective view of a portion of underground treatment system 1028 and tunnels 1034A. Tunnels 1034A, as shown in FIG. 255, may include heater tunnels 1036, utility tunnels 1038, and/or access tunnels 1040.

[1708] In certain embodiments, as shown in FIG. 254, wellbores 490 extend from heater tunnels 1036. Wellbores 490 may include, but not be limited to, heater wells, heat source wells, production wells, injection wells (for example, steam injection wells), and/or monitoring wells. Heaters and/or heat sources that may be located in wellbores 490 include, but are not limited to, electric heaters, oxidation heaters (gas burners), heaters circulating a heat transfer fluid, closed looped molten salt circulating systems, pulverized coal systems, and/or joule heat sources (heating of the formation using electrical current flow between heat sources having electrically conducting material in two wellbores in the formation). The wellbores used for joule heat sources may extend from the same tunnel (for example, substantially parallel wellbores extending between two tunnels with electrical current flowing between the wellbores) or from different tunnels (for example, wellbores extending from two different tunnels that are spaced to allow electrical current flow between the wellbores).

[1709] Heating the formation with heat sources having electrically conducting material may increase permeability in the formation and/or lower viscosity of hydrocarbons in the formation. Heat sources with electrically conducting material may allow current to flow through the formation from one heat source to another heat source. Heating using current flow or "joule heating" through the formation may heat portions of the hydrocarbon layer in a shorter amount of time relative to heating the hydrocarbon layer using conductive heating between heaters spaced apart in the formation.

[1710] In certain embodiments, subsurface formations (for example, tar sands or heavy hydrocarbon formations) include dielectric media. Dielectric media may exhibit conductivity, relative dielectric constant, and loss tangents at temperatures below 100 °C. Loss of conductivity, relative dielectric constant, and dissipation factor may occur as the formation is heated to temperatures above 100 °C due to the loss of moisture contained in the interstitial spaces in the rock matrix of the formation. To prevent loss of moisture, formations may be heated at temperatures and pressures that minimize vaporization of water. In some embodiments, conductive solutions are added to the formation to help maintain the electrical properties of the

formation. Heating the formation at low temperatures may require the hydrocarbon layer to be heated for long periods of time to produce permeability and/or injectivity.

[1711] In some embodiments, formations are heated using joule heating to temperatures and pressures that vaporize the water and/or conductive solutions. Material used to produce the current flow, however, may become damaged due to heat stress and/or loss of conductive solutions may limit heat transfer in the layer. In addition, when using current flow or joule heating, magnetic fields may form. Due to the presence of magnetic fields, non-ferromagnetic materials may be desired for overburden casings. Although many methods have been described for heating formations using joule heating, efficient and economic methods of heating and producing hydrocarbons using heat sources with electrically conductive material are needed.

[1712] In some embodiments, heat sources that include electrically conductive materials are positioned in the hydrocarbon layer. Electrically resistive portions of the hydrocarbon layer may be heated by electrical current that flows from the heat sources and through the layer. Positioning of electrically conductive heat sources in the hydrocarbon layer at depths sufficient to minimize loss of conductive solutions may allow hydrocarbons layers to be heated at relatively high temperatures over a period of time with minimal loss of water and/or conductive solutions.

[1713] Introduction of heat sources into hydrocarbon layer 388 through heater tunnels 1036 allows the hydrocarbon layer to be heated without significant heat losses to overburden 400. Being able to provide heat mainly to hydrocarbon layer 388 with low heat losses in the overburden may enhance heater efficiency. Using tunnels to provide heater sections only in the hydrocarbon layer, and not requiring heater wellbore sections in the overburden, may decrease heater costs by at least 30%, at least 50%, at least 60%, or at least 70% as compared to heater costs using heaters that have sections passing through the overburden.

[1714] In some embodiments, providing heaters through tunnels allows higher heat source densities in the hydrocarbon layer 388 to be obtained. Higher heat source densities may result in faster production of hydrocarbons from the formation. Closer spacing of heaters may be economically beneficial due to a significantly lower cost per additional heater. For example, heaters located in the hydrocarbon layer of a tar sands formation by drilling through the overburden are typically spaced about 12 m apart. Installing heaters from tunnels may allow heaters to be spaced about 8 m apart in the hydrocarbon layer. The closer spacing may accelerate first production to about 2 years as compared to the 5 years for first production obtained from heaters that are spaced 12 m apart and accelerate completion of production to about 5 years from about 8 years. This acceleration in first production may reduce the heating requirement 5% or more.

[1715] In certain embodiments, subsurface connections for heaters or heat sources are made in heater tunnels 1036. Connections that are made in heater tunnels 1036 include, but are not limited to, insulated electrical connections, physical support connections, and instrumental/diagnostic connections. For example, electrical connection may be made between electric heater elements and bus bars located in heater tunnels 1036. The bus bars may be used to provide electrical connection to the ends of the heater elements. In certain embodiments, connections made in heater tunnels 1036 are made at a certain safety level. For example, the connections are made such that there is little or no explosion risk (or other potential hazards) in the heater tunnels because of gases from the heat sources or the heat source wellbores that may migrate to heater tunnels 1036. In some embodiments, heater tunnels 1036 are ventilated to the surface or another area to lower the explosion risk in the heater tunnels. For example, heater tunnels 1036 may be vented through utility shafts 1032.

[1716] In certain embodiments, heater connections are made between heater tunnels 1036 and utility tunnels 1038. For example, electrical connections for electric heaters extending from heater tunnels 1036 may extend through the heater tunnels into utility tunnels 1038. These connections may be substantially sealed such that there is little or no leaking between the tunnels either through or around the connections.

[1717] In certain embodiments, utility tunnels 1038 include power equipment or other equipment necessary to operate heat sources and/or production equipment. In certain embodiments, transformers 1042 and voltage regulators 1044 are located in utility tunnels 1038. Locating transformers 1042 and voltage regulators 1044 in the subsurface allows high-voltages to be transported directly into the overburden of the formation to increase the efficiency of providing power to heaters in the formation.

[1718] Transformers 1042 may be, for example, gas insulated, water cooled transformers such as SF_6 gas-insulated power transformers available from Toshiba Corporation (Tokyo, Japan). Such transformers may be high efficiency transformers. These transformers may be used to provide electricity to multiple heaters in the formation. The higher efficiency of these transformers reduces water cooling requirements for the transformers. Reducing the water cooling requirements of the transformers allows the transformers to be placed in small chambers without the need for extra cooling to keep the transformers from overheating. Water cooling instead of air cooling allows more heat per volume of cooling fluid to be transported to the surface versus air cooling. Using gas-insulated transformers may eliminate the use of flammable oils that may be hazardous in the underground environment.

[1719] In some embodiments, voltage regulators 238 are distribution type voltage regulators to control the voltage distributed to heat sources in the tunnels. In some embodiments, transformers

236 are used with load tap changers to control the voltage distributed to heat sources in the tunnels. In some embodiments, variable voltage, load tap changing transformers located in utility tunnels 232 are used to distribute electrical power to, and control the voltage of, heat sources in the tunnels. Transformers 236, voltage regulators 238, load tap changers 1042, and/or variable voltage, load tap changing transformers may control the voltage distributed to either groups or banks of heat sources in the tunnels or individual heat sources. Controlling the voltage distributed to a group of heat sources provides block control for the group of heat sources. Controlling the voltage distributed to individual heat sources provides individual heat source control.

[1720] In some embodiments, transformers 1042 and/or voltage regulators 1044 are located in side chambers of utility tunnels 1038. Locating transformers 1042 and/or voltage regulators 1044 in side chambers moves the transformers and/or voltage regulators out of the way of personnel, equipment, and/or vehicles moving through utility tunnels 1038. Supply lines (for example, supply lines 204 depicted in FIG. 261) in utility shaft 1032 may supply power to voltage regulators 1044 and transformers 1042 in utility tunnels 1038.

[1721] In some embodiments, such as shown in FIG. 254, voltage regulators 1044 are located in power chambers 1046. Power chambers 1046 may connect to utility tunnels 1038 or be side chambers of the utility tunnels. Power may be brought into power chambers 1046 through utility shafts 1032. Use of power chambers 1046 may allow easier, quicker, and/or more effective maintenance, repair, and/or replacement of the connections made to heat sources in the subsurface.

[1722] In certain embodiments, sections of heater tunnels 1036 and utility tunnels 1038 are interconnected by connecting tunnels 1048. Connecting tunnels 1048 may allow access between heater tunnels 1036 and utility tunnels 1038. Connecting tunnels 1048 may include airlocks or other structures to provide a seal that can be opened and closed between heater tunnels 1036 and utility tunnels 1038.

[1723] In some embodiments, heater tunnels 1036 include pipelines 208 or other conduits. In some embodiments, pipelines 208 are used to produce fluids (for example, formation fluids such as hydrocarbon fluids) from production wells or heater wells coupled to heater tunnels 1036. In some embodiments, pipelines 208 are used to provide fluids used in production wells or heater wells (for example, heat transfer fluids for circulating fluid heaters or gas for gas burners). Pumps and associated equipment 1050 for pipelines 208 may be located in pipeline chambers 1052 or other side chambers of the tunnels. In some embodiments, pipeline chambers 1052 are isolated (sealed off) from heater tunnels 1038. Fluids may be provided to and/or removed from pipeline chambers 1052 using risers and/or pumps located in utility shafts 1032.

[1724] In some embodiments, heat sources are used in wellbores 490 proximate heater tunnels 1036 to control viscosity of formation fluids being produced from the formation. The heat sources may have various lengths and/or provide different amounts of heat at different locations in the formation. In some embodiments, the heat sources are located in wellbores 490 used for producing fluids from the formation (for example, production wells).

[1725] As shown in FIG. 253, wellbores 490 may extend between tunnels 1034A in hydrocarbon layer 388. Tunnels 1034A may include one or more of heater tunnels 1036, utility tunnels 1038, and/or access tunnels 1040. In some embodiments, access tunnels 1040 are used as ventilation tunnels. It should be understood that the any number of tunnels and/or any order of tunnels may be used as contemplated or desired.

[1726] In some embodiments, heated fluid may flow through wellbores 490 or heat sources that extend between tunnels 1034A. For example, heated fluid may flow between a first heater tunnel and a second heater tunnel. The second tunnel may include a production system that is capable of removing the heated fluids from the formation to the surface of the formation. In some embodiments, the second tunnel includes equipment that collects heated fluids from at least two wellbores. In some embodiments, the heated fluids are moved to the surface using a lift system. The lift system may be located in utility shaft 1032 or a separate production wellbore.

[1727] Production well lift systems may be used to efficiently transport formation fluid from the bottom of the production wells to the surface. Production well lift systems may provide and maintain the maximum required well drawdown (minimum reservoir producing pressure) and producing rates. The production well lift systems may operate efficiently over a wide range of high temperature/multiphase fluids (gas/vapor/steam/water/hydrocarbon liquids) and production rates expected during the life of a typical project. Production well lift systems may include dual concentric rod pump lift systems, chamber lift systems and other types of lift systems.

[1728] FIG. 256 depicts a side view representation of an embodiment for flowing heated fluid in heat sources 202 between tunnels 1034A. FIG. 257 depicts a top view representation of the embodiment depicted in FIG. 256. Circulation system 706 may circulate heated fluid (for example, molten salt) through heat sources 202. Shafts 1032 and tunnels 1034A may be used to provide the heated fluid to the heat sources and return the heated fluid from the heat sources. Large diameter piping may be used in shafts 1032 and tunnels 1034A. Large diameter piping may minimize pressure drops in transporting the heated fluid through the overburden of the formation. Piping in shafts 1032 and tunnels 1034A may be insulated to inhibit heat losses in the overburden.

[1729] FIG. 258 depicts another perspective view of an embodiment of underground treatment system 1028 with wellbores 490 extending between tunnels 1034A. Heat sources or heaters may

be located in wellbores 490. In certain embodiments, wellbores 490 extend from wellbore chambers 1054. Wellbore chambers 1054 may be connected to the sides of tunnels 1034A or be side chambers of the tunnels.

[1730] FIG. 259 depicts a top view of an embodiment of tunnel 1034A with wellbore chambers 1054. In certain embodiments, power chambers 1046 are connected to utility tunnel 1038. Transformers 1042 and/or other power equipment may be located in power chambers 1046.

[1731] In certain embodiments, tunnel 1034A includes heater tunnel 1036 and utility tunnel 1038. Heater tunnel 1036 may be connected to utility tunnel 1038 with connecting tunnel 1048. Wellbore chambers 1054 are connected to heater tunnel 1036. In certain embodiments, wellbore chambers 1054 include heater wellbore chambers 1054A and adjunct wellbore chambers 1054B. Heat sources 202 (for example, heaters) may extend from heater wellbore chambers 1054A. Heat sources 202 may be located in wellbores extending from heater wellbore chambers 1054A.

[1732] In certain embodiments, heater wellbore chambers 1054A have angled side walls with respect to heater tunnel 1036 to allow heat sources to be installed into the chambers more easily. The heaters may have limited bending capability and the angled walls may allow the heaters to be installed into the chambers without overbending the heaters.

[1733] In certain embodiments, barrier 1056 seals off heater wellbore chambers 1054A from heater tunnel 1036. Barrier 1056 may be a fire and/or blast resistant barrier (for example, a concrete wall). In some embodiments, barrier 1056 includes an access port (for example, an access door) to allow entry into the chambers. In some embodiments, heater wellbore chambers 1054A are sealed off from heater tunnel 1036 after heat sources 202 have been installed. Utility shaft 1032 may provide ventilation into heater wellbore chambers 1054A. In some embodiments, utility shaft 1032 is used to provide a fire or blast suppression fluid into heater wellbore chambers 1054A.

[1734] In certain embodiments, adjunct wellbores 490A extend from adjunct wellbore chambers 1054B. Adjunct wellbores 490A may include wellbores used as, for example, infill wellbores (repair wellbores) or intervention wellbores for killing leaks and/or monitoring wellbores. Barrier 1056 may seal off adjunct wellbore chambers 1054B from heater tunnel 1036. In some embodiments, heater wellbore chambers 1054A and/or adjunct wellbore chambers 1054B are cemented in (the chambers are filled with cement). Filling the chambers with cement substantially seals off the chambers from inflow or outflow of fluids.

[1735] As shown in FIGS. 253 and 258, wellbores 490 may be formed between tunnels 1034A. Wellbores 490 may be formed substantially vertically, substantially horizontally, or inclined in hydrocarbon layer 388 by drilling into the hydrocarbon layer from tunnels 1034A. Wellbores 490 may be formed using drilling techniques known in the art. For example, wellbores 490 may

be formed by pneumatic drilling using coiled tubing available from Penguin Automated Systems (Naughton, Ontario, Canada).

[1736] Drilling wellbores 490 from tunnels 1034A may increase drilling efficiency and decrease drilling time and allow for longer wellbores because the wellbores do not have to be drilled through overburden 400. Tunnels 1034A may allow large surface footprint equipment to be placed in the subsurface instead of at the surface. Drilling from tunnels 1034A and subsequent placement of equipment and/or connections in the tunnels may reduce a surface footprint as compared to conventional surface drilling methods that use surface based equipment and connections.

[1737] Using shafts and tunnels in combination with the in situ heat treatment process for treating the hydrocarbon containing formation may be beneficial because the overburden section is eliminated from wellbore construction, heater construction, and/or drilling requirements. In some embodiments, at least a portion of the shafts and tunnels are located below aquifers in or above the hydrocarbon containing formation. Locating the shafts and tunnels below the aquifers may reduce contamination risk to the aquifers, and/or may simplify abandonment of the shafts and tunnels after treatment of the formation.

[1738] In certain embodiments, underground treatment system 1028 (depicted in FIGS. 253, 254, 258, 262, and 261) includes one or more seals to seal the tunnels and shafts from the formation pressure and formation fluids. For example, the underground treatment system may include one or more impermeable barriers to seal personnel workspace from the formation. In some embodiments, wellbores are sealed off with impermeable barriers to the tunnels and shafts to inhibit fluids from entering the tunnels and shafts from the wellbores. In some embodiments, the impermeable barriers include cement or other packing materials. In some embodiments, the seals include valves or valve systems, airlocks, or other sealing systems known in the art. The underground treatment system may include at least one entry/exit point to the surface for access by personnel, vehicles, and/or equipment.

[1739] FIG. 260 depicts a top view of an embodiment of development of tunnel 1034A. Heater tunnel 1036 may include heat source section 1058, connecting section 1060, and/or drilling section 1062 as the heater tunnel is being formed left to right. From heat source section 1058, wellbores 490 have been formed and heat sources have been introduced into the wellbores. In some embodiments, heat source section 1058 is considered a hazardous confined space. Heat source section 1058 may be isolated from other sections in heater tunnel 1036 and/or utility tunnel 1038 with material impermeable to hydrocarbon gases and/or hydrogen sulfide. For example, cement or another impermeable material may be used to seal off heat source section 1058 from heater tunnel 1036 and/or utility tunnel 1038. In some embodiments, impermeable

material is used to seal off heat source section 1058 from the heated portion of the formation to inhibit formation fluids or other hazardous fluids from entering the heat source section. In some embodiments, at least 30 m, at least 40 m, or at least 50 m of wellbore is between the heat sources and heater tunnel 1036. In some embodiments, shaft 1030 proximate to heater tunnel 1036 is sealed (for example, filled with cement) after heating has been initiated in the hydrocarbon layer to inhibit gas or other fluids from entering the shaft.

[1740] In some embodiments, heaters controls may be located in utility tunnel 1038. In some embodiments, utility tunnel 1038 includes electrical connections, combustors, tanks, and/or pumps necessary to support heaters and/or heat transport systems. For example, transformers 1042 may be located in utility tunnel 1038.

[1741] Connecting section 1060 may be located after heat source section 1058. Connecting section 1060 may include space for performing operations necessary for installing the heat sources and/or connecting heat sources (for example, making electrical connections to the heaters). In some embodiments, connections and/or movement of equipment in connecting section 1060 is automated using robotics or other automation techniques. Drilling section 1062 may be located after connecting section 1060. Additional wellbores may be dug and/or the tunnel may be extended in drilling section 1062.

[1742] In certain embodiments, operations in heat source section 1058, connecting section 1060, and/or drilling section 1062 are independent of each other. Heat source section 1058, connecting section 1060, and/or production section 1062 may have dedicated ventilation systems and/or connections to utility tunnel 1038. Connecting tunnels 1048 may allow access and egress to heat source section 1058, connecting section 1060, and/or drilling section 1062.

[1743] In certain embodiments, connecting tunnels 1048 include airlocks 1064 and/or other barriers. Airlocks 1064 may help regulate the relative pressures such that the pressure in heat source section 1058 is less than the air pressure in connecting section 1060, which is less than the air pressure in drilling section 1062. Air flow may move into heat source section 1058 (the most hazardous area) to reduce the probability of a flammable atmosphere in utility tunnel 1038, connecting section 1060, and/or drilling section 1062. Airlocks 1064 may include suitable gas detection and alarms to ensure transformers or other electrical equipment are de-energized in the event that an unsafe flammable limit is encountered in the utility tunnel 1038 (for example, less than one-half of the lower flammable limit). Automated controls may be used to operate airlocks 1064 and/or the other barriers. Airlocks 1064 may be operated to allow personnel controlled access and/or egress during normal operations and/or emergency situations.

[1744] In certain embodiments, heat sources located in wellbores extending from tunnels are used to heat the hydrocarbon layer. The heat from the heat sources may mobilize hydrocarbons

in the hydrocarbon layer and the mobilized hydrocarbons flow towards production wells. Production wells may be positioned in the hydrocarbon layer below, adjacent, or above the heat sources to produce the mobilized fluids. In some embodiments, formation fluids may gravity drain into tunnels located in the hydrocarbon layer. Production systems may be installed in the tunnels (for example, pipeline 208 depicted in FIG. 254). The tunnel production systems may be operated from surface facilities and/or facilities in the tunnel. Piping, holding facilities, and/or production wells may be located in a production portion of the tunnels to be used to produce the fluids from the tunnels. The production portion of the tunnels may be sealed with an impervious material (for example, cement or a steel liner). The formation fluids may be pumped to the surface through a riser and/or vertical production well located in the tunnels. In some embodiments, formation fluids from multiple horizontal production wellbores drain into one vertical production well located in one tunnel. The formation fluids may be produced to the surface through the vertical production well.

[1745] In some embodiments, a production wellbore extending directly from the surface to the hydrocarbon layer is used to produce fluids from the hydrocarbon layer. FIG. 261 depicts production well 206 extending from the surface into hydrocarbon layer 388. In certain embodiments, production well 206 is substantially horizontally located in hydrocarbon layer 388. Production well 206 may, however, have any orientation desired. For example, production well 206 may be a substantially vertical production well.

[1746] In some embodiments, as shown in FIG. 261, production well 206 extends from the surface of the formation and heat sources 202 extend from tunnels 1034A in overburden 400 or another impermeable layer of the formation. Having the production well separated from the tunnels used to provide heat sources into the formation may reduce risks associated with having hot formation fluids (for example, hot hydrocarbon fluids) in the tunnels and near electrical equipment or other heater equipment. In some embodiments, the distance between the location of production wells on the surface and the location of fluid intakes, ventilation intakes, and/or other possible intakes into the tunnels below the surface is maximized to minimize the risk of fluids reentering the formation through the intakes.

[1747] In some embodiments, wellbores 490 interconnect with utility tunnels 1038 or other tunnels below the overburden of the formation. FIG. 262 depicts a side view of an embodiment of underground treatment system 1028. In certain embodiments, wellbores 490 are directionally drilled to utility tunnels 1038 in hydrocarbon layer 388. Wellbores 490 may be directional drilled from the surface or from tunnels located in overburden 400. Directional drilling to intersect utility tunnel 1038 in hydrocarbon layer 388 may be easier than directional drilling to intersect another wellbore in the formation. Drilling equipment such as, but not limited to,

magnetic transmission equipment, magnetic sensing equipment, acoustic transmission equipment, and acoustic sensing equipment may be located in utility tunnels 1038 and used for directional drilling of wellbores 490. The drilling equipment may be removed from utility tunnels 1038 after directional drilling is completed. In some embodiments, utility tunnels 1038 are later used for collection and/or production of fluids from the formation during the in situ heat treatment process.

Examples

[1748] Non-restrictive examples are set forth below.

Samples using fitting embodiment depicted in FIG. 41

[1749] Samples using an embodiment of fitting 422 similar to the embodiment depicted in FIG. 41 were fabricated using a hydraulic compaction machine with a medium voltage insulated conductor suitable for use as a subsurface heater on one side of the fitting and a medium voltage insulated conductor suitable for use as an overburden cable on the other side of the fitting. Magnesium oxide was used as the electrically insulating material in the fittings. The samples were 6 feet long from the end of one mineral insulated conductor to the other. Prior to electrical testing, the samples were placed in a 6-1/2 ft long oven and dried at 850 °F for 30 hours. Upon cooling to 150 °F, the ends of the mineral insulated conductors were sealed using epoxy. The samples were then placed in an oven 3 feet long to heat up the samples and voltage was applied to the samples using a 5 kV (max) hipot (high potential) tester, which was able to measure both total and real components of the leakage current. Three thermocouples were placed on the samples and averaged for temperature measurement. The samples were placed in the oven with the fitting at the center of the oven. Ambient DC (direct current) responses and AC (alternating current) leakage currents were measured using the hipot tester.

[1750] A total of eight samples were tested at about 1000 °F and voltages up to 5 kV. One individual sample tested at 5 kV had a leakage current of 2.28 mA, and another had a leakage current of 6.16 mA. Three more samples with conductors connected together in parallel were tested to 5 kV and had an aggregate leakage current of 11.7 mA, or 3.9 mA average leakage current per cable, and the three samples were stable. Three other samples with conductors connected together in parallel were tested to 4.4 kV and had an aggregate leakage current of 4.39 mA, but they could not withstand a higher voltage without tripping the hipot tester (which occurs when leakage current exceeds 40 mA). One of the samples tested to 5 kV underwent further testing at ambient temperature to breakdown. Breakdown occurred at 11 kV.

[1751] A total of eleven more samples were fabricated for additional breakdown testing at ambient temperature. Three of the samples had insulated conductors prepared with the mineral insulation cut perpendicular to the sheath while the eight other samples had insulated conductors prepared with the mineral insulation cut at a 30° angle to the sheath. Of the first three samples with the perpendicular cut, the first sample withstood up to 10.5 kV before breakdown, the second sample withstood up to 8 kV before breakdown, while the third sample withstood only 500 V before breakdown, which suggested a flaw in fabrication of the third sample. Of the eight samples with the 30° cut, two samples withstood up to 10 kV before breakdown, three samples withstood between 8 kV and 9.5 kV before breakdown, and three samples withstood no voltage or less than 750 V, which suggested flaws in fabrication of these three samples.

Samples using fitting embodiment depicted in FIG. 44B

[1752] Three samples using an embodiment of fitting 442 similar to the embodiment depicted in FIG. 44B were made. The samples were made with two insulated conductors instead of three and were tested to breakdown at ambient temperature. One sample withstood 5 kV before breakdown, a second sample withstood 4.5 kV before breakdown, and a third sample could withstand only 500 V, which suggested a flaw in fabrication.

Samples using fitting embodiment depicted in FIGS. 50 and 51

[1753] Samples using an embodiment of fitting 470 similar to the embodiment depicted in FIGS. 50 and 51 were used to connect two insulated conductors with 1.2" outside diameters and 0.7" diameter conductors. MgO powder (Muscle Shoals Minerals, Greenville, Tennessee, U.S.A.) was used as the electrically insulating material. The fitting was made from 347H stainless steel tubing and had an outside diameter of 1.5" with a wall thickness of 0.125" and a length of 7.0". The samples were placed in an oven and heated to 1050 °F and cycled through voltages of up to 3.4 kV. The samples were found to viable at all the voltages but could not withstand higher voltages without tripping the hipot tester.

[1754] In a second test, samples similar to the ones described above were subjected to a low cycle fatigue-bending test and then tested electrically in the oven. These samples were placed in the oven and heated to 1050 °F and cycled through voltages of 350 V, 600 V, 800 V, 1000 V, 1200 V, 1400 V, 1600 V, 1900 V, 2200 V, and 2500 V. Leakage current magnitude and stability in the samples were acceptable up to voltages of 1900 V. Increases in the operating range of the fitting may be feasible using further electric field intensity reduction methods such as tapered, smoothed, or rounded edges in the fitting or adding electric field stress reducers inside the fitting.

Examples for Semiconductor Layer in Insulated Conductor

[0100] COMSOL® simulations were used to assess the electric field effects of using a semiconductor layer in an insulated conductor heater such as those depicted in FIGS. 30 and 31. In a first simulation, electric field components were calculated for an insulated conductor heater with an irregular nickel copper core surface (a wavy core surface) surrounded by a $BaTiO_3$ semiconductor layer either on the surface of the core (as shown in FIG. 30) or in the magnesium oxide electrical insulator (as shown in FIG. 31). Electric field components were also calculated for a base case with no semiconductor layer.

[0101] FIG. 263 depicts the electric field normal component (V/m) as a function of the location along the length of the heater (m). Curve 1372 depicts the electric field for the base case. Curve 1374 depicts the electric field for the semiconductor layer on the surface. Curve 1376 depicts the electric field for the semiconductor layer in the electrical insulator. As shown in FIG. 263, having the semiconductor layer on the surface of the core is best for mitigating electric field fluctuations (least variation in electric field normal component) due to the irregular (wavy) surface of the core.

[0102] In a second simulation, electric field strengths were calculated for an insulated conductor heater with a nickel copper core surface having a defect (a notch in the core surface) surrounded by a $BaTiO_3$ semiconductor layer either on the surface of the core (as shown in FIG. 30) or in the magnesium oxide electrical insulator (as shown in FIG. 31). Electric field strength was also calculated for a base case with no semiconductor layer.

[0103] FIG. 264 depicts the electric field strength (V/m) versus distance from the core (m). Curve 1378 depicts the electric field strength for the base case. Curve 1380 depicts the electric field strength for the semiconductor layer on the surface. Curve 1382 depicts the electric field strength for the semiconductor layer in the electrical insulator. As shown in FIG. 264, the electric field strength is reduced near the core with the semiconductor layer on the surface (curve 1380).

[0104] Analytical calculations were used to assess electrical properties and the effectiveness of the semiconductor layer for an insulated conductor heater as shown in FIG. 30. FIG. 265 depicts percent of maximum unscreened (no semiconductor layer) field strength (left axis) and normalized semiconductor layer thickness (right axis) versus dielectric constant ratio of the electrical insulator and semiconductor layer ((dielectric constant of electrical insulator)/(dielectric constant of semiconductor layer)). As shown in FIG. 265, for a selected dielectric constant ratio (as shown by the vertical arrow), there corresponds a semiconductor layer thickness that minimizes the maximum electric field.

[0105] FIG. 266 depicts electric field strength (V/inch) versus normalized distance from the core for several dielectric constant ratios. Curve 1384 depicts electric field strength for a dielectric constant ratio of 0.1. Curve 1386 depicts electric field strength for a dielectric constant ratio of 0.5. Curve 1388 depicts electric field strength for a dielectric constant ratio of 0.676. Curve 1390 depicts electric field strength for a dielectric constant ratio of 0.8. Curve 1392 depicts electric field strength for an insulated conductor heater without a semiconductor layer (a dielectric strength ratio of 1). As shown in FIG. 266, the lowest maximum electric field strength between the core and the jacket (sheath) is achieved with a dielectric constant ratio of 0.676 (curve 1388).

Tar Sands Simulation

[1755] A STARS simulation was used to simulate heating of a tar sands formation using the heater well pattern depicted in FIG. 117. The heaters had a horizontal length in the tar sands formation of 600 m. The heating rate of the heaters was about 750 W/m. Production well 206B, depicted in FIG. 117, was used at the production well in the simulation. The bottom hole pressure in the horizontal production well was maintained at about 690 kPa. The tar sands formation properties were based on Athabasca tar sands. Input properties for the tar sands formation simulation included: initial porosity equals 0.28; initial oil saturation equals 0.8; initial water saturation equals 0.2; initial gas saturation equals 0.0; initial vertical permeability equals 250 millidarcy; initial horizontal permeability equals 500 millidarcy; initial K_v/K_h equals 0.5; hydrocarbon layer thickness equals 28 m; depth of hydrocarbon layer equals 587 m; initial reservoir pressure equals 3771 kPa; distance between production well and lower boundary of hydrocarbon layer equals 2.5 meter; distance of topmost heaters and overburden equals 9 meter; spacing between heaters equals 9.5 meter; initial hydrocarbon layer temperature equals 18.6 °C; viscosity at initial temperature equals 53 Pa·s (53000 cp); and gas to oil ratio (GOR) in the tar equals 50 standard cubic feet/standard barrel. The heaters were constant wattage heaters with a highest temperature of 538 °C at the sand face and a heater power of 755 W/m. The heater wells had a diameter of 15.2 cm.

[1756] FIG. 267 depicts a temperature profile in the formation after 360 days using the STARS simulation. The hottest spots are at or near heaters 412. The temperature profile shows that portions of the formation between the heaters are warmer than other portions of the formation. These warmer portions create more mobility between the heaters and create a flow path for fluids in the formation to drain downwards towards the production wells.

[1757] FIG. 268 depicts an oil saturation profile in the formation after 360 days using the STARS simulation. Oil saturation is shown on a scale of 0.00 to 1.00 with 1.00 being 100% oil saturation. The oil saturation scale is shown in the sidebar. Oil saturation, at 360 days, is

somewhat lower at heaters 412 and production well 206B. FIG. 269 depicts the oil saturation profile in the formation after 1095 days using the STARS simulation. Oil saturation decreased overall in the formation with a greater decrease in oil saturation near the heaters and in between the heaters after 1095 days. FIG. 270 depicts the oil saturation profile in the formation after 1470 days using the STARS simulation. The oil saturation profile in FIG. 270 shows that the oil is mobilized and flowing towards the lower portions of the formation. FIG. 271 depicts the oil saturation profile in the formation after 1826 days using the STARS simulation. The oil saturation is low in a majority of the formation with some higher oil saturation remaining at or near the bottom of the formation in portions below production well 206B. This oil saturation profile shows that a majority of oil in the formation has been produced from the formation after 1826 days.

[1758] FIG. 272 depicts the temperature profile in the formation after 1826 days using the STARS simulation. The temperature profile shows a relatively uniform temperature profile in the formation except at heaters 412 and in the extreme (corner) portions of the formation. The temperature profile shows that a flow path has been created between the heaters and to production well 206B.

[1759] FIG. 273 depicts oil production rate 1066 (bbl/day)(left axis) and gas production rate 1068 (ft^3/day)(right axis) versus time (years). The oil production and gas production plots show that oil is produced at early stages (0-1.5 years) of production with little gas production. The oil produced during this time was most likely heavier mobilized oil that is unpyrolyzed. After about 1.5 years, gas production increased sharply as oil production decreased sharply. The gas production rate quickly decreased at about 2 years. Oil production then slowly increased up to a maximum production around about 3.75 years. Oil production then slowly decreased as oil in the formation was depleted.

[1760] From the STARS simulation, the ratio of energy out (produced oil and gas energy content) versus energy in (heater input into the formation) was calculated to be about 12 to 1 after about 5 years. The total recovery percentage of oil in place was calculated to be about 60% after about 5 years. Thus, producing oil from a tar sands formation using an embodiment of the heater and production well pattern depicted in FIG. 117 may produce high oil recoveries and high energy out to energy in ratios.

Tar Sands Example

[1761] A STARS simulation was used in combination with experimental analysis to simulate an in situ heat treatment process of a tar sands formation. Heating conditions for the experimental analysis were determined from reservoir simulations. The experimental analysis included heating a cell of tar sands from the formation to a selected temperature and then reducing the

pressure of the cell (blow down) to 100 psig. The process was repeated for several different selected temperatures. While heating the cells, formation and fluid properties of the cells were monitored while producing fluids to maintain the pressure below an optimum pressure of 12 MPa before blow down and while producing fluids after blow down (although the pressure may have reached higher pressures in some cases, the pressure was quickly adjusted and does not affect the results of the experiments). FIGS. 274-281 depict results from the simulation and experiments.

[1762] FIG. 274 depicts weight percentage of original bitumen in place (OBIP) (left axis) and volume percentage of OBIP (right axis) versus temperature (°C). The term "OBIP" refers, in these experiments, to the amount of bitumen that was in the laboratory vessel with 100% being the original amount of bitumen in the laboratory vessel. Plot 1070 depicts bitumen conversion (correlated to weight percentage of OBIP). Plot 1070 shows that bitumen conversion began to be significant at about 270 °C and ended at about 340 °C. The bitumen conversion was relatively linear over the temperature range.

[1763] Plot 1072 depicts barrels of oil equivalent from producing fluids and production at blow down (correlated to volume percentage of OBIP). Plot 1074 depicts barrels of oil equivalent from producing fluids (correlated to volume percentage of OBIP). Plot 1076 depicts oil production from producing fluids (correlated to volume percentage of OBIP). Plot 1078 depicts barrels of oil equivalent from production at blow down (correlated to volume percentage of OBIP). Plot 1080 depicts oil production at blow down (correlated to volume percentage of OBIP). As shown in FIG. 274, the production volume began to significantly increase as bitumen conversion began at about 270 °C with a significant portion of the oil and barrels of oil equivalent (the production volume) coming from producing fluids and only some volume coming from the blow down.

[1764] FIG. 275 depicts bitumen conversion percentage (weight percentage of (OBIP)) (left axis) and oil, gas, and coke weight percentage (as a weight percentage of OBIP) (right axis) versus temperature (°C). Plot 1082 depicts bitumen conversion (correlated to weight percentage of OBIP). Plot 1084 depicts oil production from producing fluids correlated to weight percentage of OBIP (right axis). Plot 1086 depicts coke production correlated to weight percentage of OBIP (right axis). Plot 1088 depicts gas production from producing fluids correlated to weight percentage of OBIP (right axis). Plot 1090 depicts oil production from blow down production correlated to weight percentage of OBIP (right axis). Plot 1092 depicts gas production from blow down production correlated to weight percentage of OBIP (right axis). FIG. 275 shows that coke production begins to increase at about 280 °C and maximizes around 340 °C. FIG. 275 also shows that the majority of oil and gas production is from produced fluids with only a small fraction from blow down production.

[1765] FIG. 276 depicts API gravity (°) (left axis) of produced fluids, blow down production, and oil left in place along with pressure (psig) (right axis) versus temperature (°C). Plot 1094 depicts API gravity of produced fluids versus temperature. Plot 1096 depicts API gravity of fluids produced at blow down versus temperature. Plot 1098 depicts pressure versus temperature. Plot 1100 depicts API gravity of oil (bitumen) in the formation versus temperature. FIG. 276 shows that the API gravity of the oil in the formation remains relatively constant at about 10° API and that the API gravity of produced fluids and fluids produced at blow down increases slightly at blow down.

[1766] FIGS. 277A-D depict gas-to-oil ratios (GOR) in thousand cubic feet per barrel (Mcf/ bbl) (y-axis) versus temperature (°C) (x-axis) for different types of gas at a low temperature blow down (about 277 °C) and a high temperature blow down (at about 290 °C). FIG. 277A depicts the GOR versus temperature for carbon dioxide (CO_2). Plot 1102 depicts the GOR for the low temperature blow down. Plot 1104 depicts the GOR for the high temperature blow down. FIG. 277B depicts the GOR versus temperature for hydrocarbons. FIG. 277C depicts the GOR for hydrogen sulfide (H_2S). FIG. 277D depicts the GOR for hydrogen (H_2). In FIGS. 277B-D, the GORs were approximately the same for both the low temperature and high temperature blow downs. The GORs for CO_2 (shown in FIGS. 277A-D) was different for the high temperature blow down and the low temperature blow down. The reason for the difference in the GORs for CO_2 may be that CO_2 was produced early (at low temperatures) by the hydrous decomposition of dolomite and other carbonate minerals and clays. At these low temperatures, there was hardly any produced oil so the GOR is very high because the denominator in the ratio is practically zero. The other gases (hydrocarbons, H_2S, and H_2) were produced concurrently with the oil either because they were all generated by the upgrading of bitumen (for example, hydrocarbons, H_2, and oil) or because they were generated by the decomposition of minerals (such as pyrite) in the same temperature range as that of bitumen upgrading. Thus, when the GOR was calculated, the denominator (oil) was non zero for hydrocarbons, H_2S, and H_2.

[1767] FIG. 278 depicts coke yield (weight percentage) (y-axis) versus temperature (°C) (x-axis). Plot 1106 depicts bitumen and kerogen coke as a weight percent of original mass in the formation. Plot 1108 depicts bitumen coke as a weight percent of original bitumen in place (OBIP) in the formation. FIG. 278 shows that kerogen coke is already present at a temperature of about 260 °C (the lowest temperature cell experiment) while bitumen coke begins to form at about 280 °C and maximizes at about 340 °C.

[1768] FIGS. 279A-D depict assessed hydrocarbon isomer shifts in fluids produced from the experimental cells as a function of temperature and bitumen conversion. Bitumen conversion and temperature increase from left to right in the plots in FIGS. 279A-D with the minimum

bitumen conversion being 10%, the maximum bitumen conversion being 100%, the minimum temperature being 277 °C, and the maximum temperature being 350 °C. The arrows in FIGS. 279A-D show the direction of increasing bitumen conversion and temperature.

[1769] FIG. 279A depicts the hydrocarbon isomer shift of n-butane-$\delta^{13}C_4$ percentage (y-axis) versus propane- $\delta^{13}C_3$ percentage (x-axis). FIG. 279B depicts the hydrocarbon isomer shift of n-pentane- $\delta^{13}C_5$ percentage (y-axis) versus propane- $\delta^{13}C_3$ percentage (x-axis). FIG. 279C depicts the hydrocarbon isomer shift of n-pentane- $\delta^{13}C_5$ percentage (y-axis) versus n-butane- $\delta^{13}C_4$ percentage (x-axis). FIG. 279D depicts the hydrocarbon isomer shift of i-pentane- $\delta^{13}C_5$ percentage (y-axis) versus i-butane- $\delta^{13}C_4$ percentage (x-axis). FIGS. 279A-D show that there is a relatively linear relationship between the hydrocarbon isomer shifts and both temperature and bitumen conversion. The relatively linear relationship may be used to assess formation temperature and/or bitumen conversion by monitoring the hydrocarbon isomer shifts in fluids produced from the formation.

[1770] FIG. 280 depicts weight percentage (Wt%)(y-axis) of saturates from SARA analysis of the produced fluids versus temperature (°C)(x-axis). The logarithmic relationship between the weight percentage of saturates and temperature may be used to assess formation temperature by monitoring the weight percentage of saturates in fluids produced from the formation.

[1771] FIG. 281 depicts weight percentage (Wt%) (y-axis) of n-C_7 of the produced fluids versus temperature (°C) (x-axis). The linear relationship between the weight percentage of n-C_7 and temperature may be used to assess formation temperature by monitoring the weight percentage of n-C_7 in fluids produced from the formation.

Pre-Heating Using Heaters For Injectivity Before Steam Drive Example

[1772] An example uses the embodiment depicted in FIGS. 123 and 124 to preheat. Injection wells 602 and production wells 206 are substantially vertical wells. Heaters 412 are long substantially horizontal heaters positioned so that the heaters pass in the vicinity of injection wells 602. Heaters 412 intersect the vertical well patterns slightly displaced from the vertical wells.

[1773] The following conditions were assumed for purposes of this example:

(a) heater well spacing; s = 330 ft;

(b) formation thickness; h = 100 ft;

(c) formation heat capacity; ρc = 35 BTU/cu. ft.-°F

(d) formation thermal conductivity; λ = 1.2 BTU/ft-hr-°F;

(e) electric heating rate; q_h = 200 watts/ft;

(f) steam injection rate; q_s = 500 bbls/day;

(g) enthalpy of steam; h_s = 1000 BTU/lb;

(h) time of heating; t = 1 year;

(i) total electric heat injection; Q_E = BTU/pattern/year;

(j) radius of electric heat; r = ft; and

(k) total steam heat injected; Q_s = BTU/pattern/year.

[1774] Electric heating for one well pattern for one year is given by:

(EQN. 12) $Q_E = q_h \cdot t \cdot s$ (BTU/pattern/year);

with Q_E = (200 watts/ft)[0.001 kw/watt](1 yr)[365 day/yr][24 hr/day][3413 BTU/kw·hr](330 ft) = 1.9733×10^9 BTU/pattern/year.

[1775] Steam heating for one well pattern for one year is given by:

(EQN. 13) $Q_s = q_s \cdot t \cdot h_s$ (BTU/pattern/year);

with Q_s = (500 bbls/day)(1 yr) [365 day/yr][1000 BTU/lb][350 lbs/bbl] = 63.875×10^9 BTU/pattern/year.

[1776] Thus, electric heat divided by total heat is given by:

(EQN. 14) $Q_E/(Q_E+Q_s) \times 100$ = 3% of the total heat.

[1777] Thus, the electrical energy is only a small fraction of the total heat injected into the formation.

[1778] The actual temperature of the region around a heater is described by an exponential integral function. The integrated form of the exponential integral function shows that about half the energy injected is nearly equal to about half of the injection well temperature. The temperature required to reduce viscosity of the heavy oil is assumed to be 500 °F. The volume heated to 500 °F by an electric heater in one year is given by:

(EQN. 15) $V_E = \pi r^2$.

[1779] The heat balance is given by:

(EQN. 16) $Q_E = (\pi r_E^2)(s)(\rho c)(\Delta T)$.

Thus, r_E can be solved for and is found to be 10.4 ft. For an electric heater operated at 1000 °F, the diameter of a cylinder heated to half that temperature for one year would be about 23 ft. Depending on the permeability profile in the injection wells, additional horizontal wells may be stacked above the one at the bottom of the formation and/or periods of electric heating may be extended. For a ten year heating period, the diameter of the region heated above 500 °F would be about 60 ft.

[1780] If all the steam were injected uniformly into the steam injectors over the 100 ft. interval for a period of one year, the equivalent volume of formation that could be heated to 500 °F would be give by:

(EQN. 17) $Q_s = (\pi r_s^2)(s)(\rho c)(\Delta T)$.

[1781] Solving for r_s gives an r_s of 107 ft. This amount of heat would be sufficient to heat about ¾ of the pattern to 500 °F.

Tar Sands Oil Recovery Example

[1782] A STARS simulation was used in combination with experimental analysis to simulate an in situ heat treatment process of a tar sands formation. The experiments and simulations were used to determine oil recovery (measured by volume percentage (vol%) of oil in place (bitumen in place)) versus API gravity of the produced fluid as affected by pressure in the formation. The experiments and simulations also were used to determine recovery efficiency (percentage of oil (bitumen) recovered) versus temperature at different pressures.

[1783] FIG. 282 depicts oil recovery (volume percentage bitumen in place (vol% BIP)) versus API gravity (°) as determined by the pressure (MPa) in the formation. As shown in FIG. 282, oil recovery decreases with increasing API gravity and increasing pressure up to a certain pressure (about 2.9 MPa in this experiment). Above that pressure, oil recovery and API gravity decrease with increasing pressure (up to about 10 MPa in the experiment). Thus, it may be advantageous to control the pressure in the formation below a selected value to get higher oil recovery along with a desired API gravity in the produced fluid.

[1784] FIG. 283 depicts recovery efficiency (%) versus temperature (°C) at different pressures. Curve 1110 depicts recovery efficiency versus temperature at 0 MPa. Curve 1112 depicts recovery efficiency versus temperature at 0.7 MPa. Curve 1114 depicts recovery efficiency versus temperature at 5 MPa. Curve 1116 depicts recovery efficiency versus temperature at 10 MPa. As shown by these curves, increasing the pressure reduces the recovery efficiency in the formation at pyrolysis temperatures (temperatures above about 300 °C in the experiment). The effect of pressure may be reduced by reducing the pressure in the formation at higher temperatures, as shown by curve 1118. Curve 1118 depicts recovery efficiency versus temperature with the pressure being 5 MPa up until about 380 °C, when the pressure is reduced to 0.7 MPa. As shown by curve 1118, the recovery efficiency can be increased by reducing the pressure even at higher temperatures. The effect of higher pressures on the recovery efficiency is reduced when the pressure is reduced before hydrocarbons (oil) in the formation have been converted to coke.

Molten Salt Circulation System Simulation

[1785] A simulation was run using molten salt in a circulation system to heat an oil shale formation. The well spacing was 30 ft, and the treatment area was 5000 ft of formation surrounding a substantially horizontal portion of the piping. The overburden had a thickness of 984 ft. The piping in the formation includes an inner conduit positioned in an outer conduit.

Adjacent to the treatment area, the outer conduit is a 4" schedule 80 pipe, and the molten salt flows through the annular region between the outer conduit and the inner conduit. Through the overburden of the formation, the molten salt flows through the inner conduit. A first fluid switcher in the piping changes the flow from the inner conduit to the annular region before the treatment area, and a second fluid switcher in the piping changes the flow from the annular region to the inner conduit after the treatment area.

[1786] FIG. 284 depicts time to reach a target reservoir temperature of 340 °C for different mass flow rates or different inlet temperatures. Curve 1120 depicts the case for an inlet molten salt temperature of 550 °C and a mass flow rate of 6 kg/s. The time to reach the target temperature was 1405 days. Curve 1122 depicts the case for an inlet molten salt temperature of 550 °C and a mass flow rate of 12 kg/s. The time to reach the target temperature was 1185 days. Curve 1124 depicts the case for an inlet molten salt temperature of 700 °C and a mass flow rate of 12 kg/s. The time to reach the target temperature was 745 days.

[1787] FIG. 285 depicts molten salt temperature at the end of the treatment area and power injection rate versus time for the cases where the inlet molten salt temperature was 550 °C. Curve 1126 depicts molten salt temperature at the end of the treatment area for the case when the mass flow rate was 6 kg/s. Curve 1128 depicts molten salt temperature at the end of the treatment area for the case when the mass flow rate was 12 kg/s. Curve 1130 depicts power injection rate into the formation (W/ft) for the case when the mass flow rate was 6 kg/s. Curve 1132 depicts power injection rate into the formation (W/ft) for the case when the mass flow rate was 12 kg/s. The circled data points indicate when heating was stopped.

[1788] FIG. 286 and FIG. 287 depicts simulation results for 8000 ft heating portions of heaters positioned in the Grosmont formation of Canada for two different mass flow rates. FIG. 286 depicts results for a mass flow rate of 18 kg/s. Curve 1134 depicts heater inlet temperature of about 540 °C. Curve 1136 depicts heater outlet temperature. Curve 1138 depicts heated volume average temperature. Curve 1140 depicts power injection rate into the formation. FIG. 287 depicts results for a mass flow rate of 12 kg/s. Curve 1142 depicts heater inlet temperature of about 540 °C. Curve 1144 depicts heater outlet temperature. Curve 1146 depicts heated volume average temperature. Curve 1148 depicts power injection rate into the formation.

[1789] This examples demonstrates a method of using a system that includes at least one fluid circulation system configured to provide hot heat transfer fluid to a plurality of heaters in the formation, and a plurality of heaters in the formation coupled to the circulation system. At least one of the heaters includes a first conduit, a second conduit positioned in the first conduit, and a first flow switcher. The flow switcher is configured to allow a fluid flowing through the second conduit to flow through the annular region between the first conduit and the second conduit.

Power Requirement Simulation

[1790] A simulation to determine the power requirements to heat a formation with a molten salt was performed. Molten salt was circulated through wellbores in a hydrocarbon containing formation and the power requirements to heat the formation using molten salt were assessed over time. The distance between the wellbores was varied to determine the effect upon the power requirements.

[1791] FIG. 288 depicts curve 1150 of power (W/ft)(y-axis) versus time (yr)(x-axis) of in situ heat treatment power injection requirements. FIG. 289 depicts power (W/ft)(y-axis) versus time (days)(x-axis) of in situ heat treatment power injection requirements for different spacings between wellbores. Curves 1152-1160 depict the results in FIG. 289. Curve 1152 depicts power required versus time for heater wellbores with a spacing of about 14.4 meters. Curve 1154 depicts power required versus time for heater wellbores with a spacing of about 13.2 meters. Curve 1156 depicts power required versus time for the Grosmont formation in Alberta, Canada, with heater wellbores laid out in a hexagonal pattern and with a spacing of about 12 meters. Curve 1158 depicts power required versus time for heater wellbores with a spacing of about 9.6 meters. Curve 1160 depicts power required versus time for heater wellbores with a spacing of about 7.2 meters.

[1792] From the graph in FIG. 289, wellbore spacing represented by curve 1158 is the spacing which approximately correlates to the power output over time of certain nuclear reactors (for example, at least some nuclear reactors having a power output that decays at a rate of about 1/E, for example, in about 4 to 9 years). Curves 1152-1156, in FIG. 289, depict the required power output for heater wellbores with spacing ranging from about 12 meters to about 14.4 meters. Spacing between heater wellbores greater than about 12 meters may require more power input than certain nuclear reactors may be able to provide. Spacing between heater wellbores less than about 8 meters (for example, as represented by curve 1160 in FIG. 289) may not make efficient use of the power input provided by certain nuclear reactors.

[1793] FIG. 290 depicts reservoir average temperature (°C)(y-axis) versus time (days)(x-axis) of in situ heat treatment for different spacings between wellbores. Curves 1152-1160 depict the temperature increase in the formation over time based upon the power input requirements for the well spacing. A target temperature for in situ heat treatment of hydrocarbon containing formations, in some embodiments, for example may be about 350 °C. The target temperature for a formation may vary depending on, at least, the type of formation and/or the desired hydrocarbon products. The spacing between the wellbores for curves 1152-1160 in FIG. 290 are the same for curves 1152-1160 in FIG. 289. Curves 1152-1156, in FIG. 290, depict the increasing temperature in the formation over time for heater wellbores with spacing ranging from

about 12 meters to about 14.4 meters. Spacing between heater wellbores greater than about 12 meters may heat the formation too slowly such that more energy may be required than certain nuclear reactors may be able to provide (especially after about 5 years in the current example). Spacing between heater wellbores less than about 8 meters (for example, as represented by curve 1160 in FIG. 290) may heat the formation too quickly for some in situ heat treatment situations. From the graph in FIG. 290, wellbore spacing represented by curve 1158 may be the spacing that achieves a typical target temperature of about 350 °C in a desirable time frame (for example, about 5 years).

Aqueous Molten Salt Simulation

[1794] A simulation was run to simulate forming a heat transfer fluid in a circulation system to heat a subsurface formation. The well spacing was 50 ft and the treatment area was 2000 ft of formation surrounding a substantially horizontal portion of the piping. The overburden had a thickness of 1400 ft. The heater in the formation was L-shaped and included an inlet conduit and an outlet conduit. Adjacent to the treatment area, the outlet conduit was a 6" schedule 80 pipe, and included two insulated pipes that formed a channel (inlet conduit) inside the pipe. The heat transfer fluid flowed down the inlet conduit and back up through the annulus (outlet conduit) between the outside of the two inner pipes and the inner walls of the 6" pipe. Initially, water was circulated at ambient temperatures through the circulation system. While circulating, the temperature of the water was raised to about 100 °C. Solar salt was added to the circulating system over a period of 48 hours to form an aqueous molten salt mixture. The temperature of the solution was raised over time to evaporate the water from the salt solution to form the molten salt.

[1795] FIG. 291 depicts time (hour) versus temperature (°C) and molten salt concentration in weight percent. Curve 1162 depicts salt concentration over time. Curve 1164 depicts temperatures at the inlet of the inlet conduit over time. Curve 1166 depicts the temperature at the outlet of the outlet conduit over time. Curve 1168 depicts the aqueous molten salt mixture temperature over time. Data point 1170 depicts the start of the addition of the salt into water circulating through the piping. Data point 1172 depicts the temperature at which water starts to evaporate. The shaded area between curves 1164 and 1166 depicts the amount of energy delivered to the section of the formation to be heated. The shaded area between curves 1166 and 1168 depicts the amount of energy used for evaporation of water from the aqueous molten salt mixture. FIG. 292 depicts heat transfer rates versus time. Curve 1174 depicts rate of heat transfer to the portion of the formation to be heated over time. Curve 1176 depicts rate of heat loss to the overburden over time.

[1796] This example demonstrates a method of heating a subsurface formation that includes circulating a first heat transfer fluid through piping positioned in a wellbore; heating at least a portion of the first heat transfer fluid; and adding one or more salts to the heated portion of the first heat transfer fluid to form a heated salt solution. The salt solution contains the first heat transfer fluid and the one or more salts. At least a portion of a formation is heated to a first temperature with the heated salt solution. At least a portion of the first heat transfer fluid is removed to form a second heat transfer fluid. The portion of the formation is heated to a second temperature with the second heat transfer fluid with the second temperature being higher than the first temperature.

Subsurface Deasphalting

[1797] STARS® simulations including a PVT/kinetic model were used to assess the subsurface deasphalting of formation fluid. FIG. 293 is a graphical representation of asphaltene H/C molar ratios of hydrocarbons having a boiling point greater than 520 °C versus time (days). Data 1478 represents predicted asphaltene H/C molar ratios for hydrocarbons having a boiling point greater than 520 °C obtained from a formation heated by an in situ heat treatment process. As shown from data 1478, the asphaltene H/C molar ratios of hydrocarbons having a boiling point greater than 520 °C changes over time. Specifically, it is predicted that the asphaltene H/C molar ratio falls below 1 being seen after a heating for a period of time. Data 1480 represents predicted asphaltene H/C molar ratios for hydrocarbons having a boiling point greater than 520 °C of hydrocarbons during treatment of the formation using an in situ heat treatment process under deasphalting conditions as described by the equation:

EQN. 18:

$$SR(H/C)\text{"}deasphalted\text{"} = m_1 * SR(H/C)_{from\ STARS} + m_2 * \left[\frac{vol\,(naphtha/\text{kerosene})_{in\ liquid\ phase}}{vol\ SR}\right]_{from\ STARS} + b$$

where SR is hydrocarbons having a boiling point greater than 520 °C, m_1 = 0.243, m_2 =0.84, and b =0.99.

[1798] . 1482 represents measured asphaltene H/C molar ratios for hydrocarbons having a boiling point greater than 520 °C after treating of the formation using an in situ heat treatment process and subsurface deasphalting conditions. As shown in FIG. 293, the asphaltene content of hydrocarbon in the formation may be adjusted to maintain an asphaltene H/C molar ratio above 1 by varying the volume of naphtha/kerosene and/or volume of hydrocarbons having a boiling point greater than 520 °C.

ISHT Residue/Asphalt/Bitumen Composition Example

[1799] In situ heat treatment (ISHT) residue (8.2 grams) having the properties listed in TABLE 11 was added to asphalt/bitumen (91.8 grams, pen grade 160/220, Petit Couronne refinery) at 190 °C and stirred for 20 min under low shear to form a ISHT residue/asphalt/bitumen mixture. The ISHT residue/asphalt/bitumen mixture was equivalent to a 70/100 pen grade (paving grade) asphalt/bitumen. The properties of the ISHT residue/asphalt/bitumen blend are listed in TABLE 12.

TABLE 11

Properties	Value
Distillation, °C SIMDIS 750	
Initial boiling point	407
Final boiling point	>750
Saturates, Aromatics, Resins and Asphaltenes, wt% modified GSEE method (roofing felt manufacturers group	
Saturates	2.4
Aromatics	10.3
Resins	35.8
Asphaltenes	51.6
Sulfur, wt%, ASTM Test Method, D2622,	1.6
Total Nitrogen, wt%, ASTM Test Method D5762	2.4
Metals, ppm ICP, ASTM Test Method D5185	
Aluminum	2
Calcium	5
Iron	100
Potassium	9
Magnesium	<1
Sodium	10
Nickel	50
Vanadium	5
Pen @60 °C, 0.1 mm EN 1426	3
R&B Temperature, °C EN 1427	139
Relative density at 25 °C, densitymeter	1.094

TABLE 12

Properties	ISHT Residue Blend	Spec. (EN12591)
Properties of fresh blend		
Pen, 25 °C, 0.1 mm	85	70-100
Softening Point, °C	45.4	43-51
Flash point, °C	>310	>230
Fraass breaking point, °C	-26	-10
Dynamic Viscosity, Pa·s		
at 100 °C	2.3179	
at 135 °C	0.3112	
at 150 °C	0.1569	
at 170 °C	0.0711	
Properties after RTFOT ageing (EN12607-1)		
Softening point, °C	51.6	>45
Mass change, %	+0.13	<0.8
Retained pen, %	60.0	>46
Delta softening point, °C	6.2	<9

[1800] The water absorption of a concrete mixture having the components listed in TABLE 13 was determined as a function of time during immersion at a water temperature of 60 °C. Stiffness was characterized via the indirect tensile stiffness modulus (ISTM) as detailed below.

TABLE 13

Component	Mass (g)	wt %
Filler Wigro	79.8	6.7%
Drain sand	34.9	2.9%
Westerschelde sand	68.6	5.8%
Crushed sand	310.3	26.1%
2/6 Dutch Crushed Gravel	172	14.5%
4/8 Dutch Crushed Gravel	229.4	19.3%
8/11 Dutch Crushed Gravel	229.4	19.3%
ISHT residue/Bitumen blend	65.2	5.5%
Total	1189.6	100%

[1801] Asphalt Concrete Mixture.

[1802] Specimen preparation. The components in TABLE 13 were mixed at a 150 °C and compacted at a temperature of 140 °C to form cylinders having a diameter of 100 mm and a thickness of 63 mm thickness (Marshall specimens). The specimens were dried and the bulk density and voids in mixture (VIM) were determined on each specimen according to EN12697-6 and EN12697-8 respectively.

[1803] Conditioning of the specimens. Specimens were first immersed in a water bath at 4°C and vacuum was applied for a 30 minutes period in order to decrease pressure from atmospheric pressure to 2.4 kPa (24 mbar). The pressure was maintained at 2.4 kPa for 2.5 hours. The specimens were immersed in water at a temperature of 60°C for several days and then dried at room temperature.

[1804] Water adsorption was determined after vacuum treatment and after water conditioning of the specimens at 60 °C. The conditioned specimens were placed in 20 °C water for 1 hour. The specimens were removed and the amount of water absorbed was compared with the voids content of the specimen. This ratio is presented as the degree of water saturation (volume ratio in percent).

[1805] Indirect Tensile Stiffness Modulus test was performed according to EN 12697-26 annex C. The ITSM test was carried out in the Nottingham Asphalt Tester using a rise time of 124 ms, 5 μm horizontal deformation and a temperature of 20°C. The ITSM values of the dry specimens were determined after 3 hours conditioning at 20°C in air. After water conditioning, the ITSM test at 20°C was carried out rapidly after the weighting of the specimen, to avoid the loss of water. The ITSM test was also carried out during the drying period for the specimens. The results are expressed as percentage of the dry, initial ITSM value.

[1806] FIG. 294 depicts percentage of degree of saturation (volume water/air voids) versus time during immersion at a water temperature of 60 °C. FIG. 295 depicts retained indirect tensile strength stiffness modulus versus time during immersion at a water temperature of 60 °C. In FIGS. 294 and 295, plots 1178 and 1190 are 70/100 pen grade asphalt/bitumen without any adhesion improvers, plots 1180 and 1192 are a 70/100 pen grade asphalt/bitumen with 0.5% by weight acidic type adhesion improver, plots 1182 and 1194 are a 70/100 pen grade asphalt/bitumen with 1% by weight acidic type adhesion improver, plots 1184 and 1196 are a 70/100 pen grade asphalt/bitumen with 0.5% by weight amine type adhesion improver, plots 1186 and 1198 are a 70/100 pen grade asphalt/bitumen with 1% by weight amine type adhesion improver, and plots 1188 are 1200 are a ISHT/asphalt/bitumen composition. In FIG. 294, the initial rise in water absorption was due to vacuum treatment of the samples to induce water into

the asphalt/bitumen compositions. After 10 days of treatment, the ISHT/asphalt/bitumen composition (plot 1188) had similar water adsorption characteristics as the asphalt/bitumen blends containing amines and/or acidic-type adhesion improvers. In FIG. 295, ISHT/asphalt/bitumen composition (plot 1188) had similar or better retained tensile strength stiffness modulus than asphalt/bitumen blends containing amines and/or acidic-type adhesion improvers.

[1807] As shown in Tables 11 and 12 and Figures 294 and 295, an ISHT/asphalt/bitumen composition has properties suitable for use as a binder for paving, enhanced water shedding properties, and enhanced tensile strength characteristics.

[1808] It is to be understood the invention is not limited to particular systems described which may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting. As used in this specification, the singular forms "a", "an" and "the" include plural referents unless the content clearly indicates otherwise. Thus, for example, reference to "a layer" includes a combination of two or more layers and reference to "a fluid" includes mixtures of fluids.

[1809] Further modifications and alternative embodiments of various aspects of the invention may be apparent to those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as described in the following claims. In addition, it is to be understood that features described herein independently may, in certain embodiments, be combined.

CLAIMS:

1. A method for treating a tar sands formation, comprising:

providing heat from a first heater located between a steam injection well and a production well in a hydrocarbon containing layer of the formation, wherein the first heater, the steam injection well, and the production well are located substantially horizontally in the hydrocarbon containing layer;

providing heat from a second heater horizontally offset from the first heater, the second heater being located vertically above an injection/production well in the hydrocarbon containing layer, the second heater being located substantially horizontally in the hydrocarbon containing layer;

injecting steam into the hydrocarbon containing layer through the steam injection well after a selected amount of heat is provided from the first heater;

producing hydrocarbons from the layer through the production well; and

alternately injecting steam and producing hydrocarbons through the injection/production well after a selected amount of heat is provided from the second heater.

2. The method of claim 1, wherein the first heater is approximately vertically equidistant between the steam injection well and the production well.

3. The method of claim 1, wherein the steam is injected through the steam injection well at a pressure that is above the formation fracturing pressure and below the overburden fracture pressure of the formation.

4. The method of claim 1, wherein the steam is injected through the injection/production well at a pressure that is above the formation fracturing pressure and below the overburden fracture pressure of the formation.

5. The method of claim 1, wherein steam injected through the steam injection well is at about the same pressure as steam injected through the injection/production well.

6. The method of claim 1, wherein the first heater and/or the second heater are electric heaters.

7. The method of claim 1, wherein the first heater and/or the second heater provide heat at a heat injection rate of at least about 1000 watts per meter.

8. The method of claim 1, wherein the selected amount of heat provided from the first heater creates sufficient steam injectivity between the steam injection well and the production well for injection of the steam from the steam injection well to move hydrocarbons to the production well.

9. The method of claim 1, wherein the selected amount of heat provided from the first heater is reached after about one year of heating using the first heater.

10. The method of claim 1, wherein the selected amount of heat provided from the second heater creates sufficient steam injectivity around the injection/production well for injection of the steam from the injection/production well.

11. The method of claim 1, wherein the selected amount of heat provided from the second heater is reached after about one year of heating using the second heater.

12. The method of claim 1, wherein the injection/production well is located substantially horizontally in the hydrocarbon containing layer.

13. The method of claim 1, wherein the injection/production well comprises one or more substantially vertical wells located in the hydrocarbon containing layer, the second heater being located vertically above the injection/production location of the vertical wells.

14. The method of claim 1, wherein the first heater is turned off on or about the time injection of steam through the steam injection well is started.

15. The method of claim 1, wherein the second heater is turned off on or about the time steam injection interconnectivity between the injection/production well and the production well is achieved.

16. The method of claim 1, wherein the initial vertical permeability in the hydrocarbon containing layer is at most about 300 millidarcy.

17. The method of claim 1, wherein the initial horizontal permeability in the hydrocarbon containing layer is at most about 1 darcy.

18. The method of claim 1, wherein the initial viscosity in the hydrocarbon containing layer is at least about 1×10^6 centipoise.

19. The method of claim 1, wherein the hydrocarbon containing layer has an initial permeability that is heterogenous.

20. The method of claim 1, wherein providing heat to the hydrocarbon containing layer from the first heater and/or the second heater increases the steam injectivity in the layer.

21. A method for treating a tar sands formation, comprising:

providing heat from a first heater located between a steam injection well and a production well in a hydrocarbon containing layer of the formation, wherein the first heater, the steam injection well, and the production well are located substantially horizontally in the hydrocarbon containing layer;

injecting steam into the hydrocarbon containing layer through the steam injection well after a selected amount of heat is provided from the first heater; and

producing hydrocarbons from the layer through the production well.

22. The method of claim 21, wherein the first heater is approximately vertically equidistant between the steam injection well and the production well.

23. The method of claim 21, wherein the steam is injected through the steam injection well at a pressure that is above the formation fracturing pressure and below the overburden fracture pressure of the formation.

24. The method of claim 21, wherein the first heater is an electric heater.

25. The method of claim 21, wherein the first heater provides heat at a heat injection rate of at least about 1000 watts per meter.

26. The method of claim 21, wherein the selected amount of heat provided from the first heater creates sufficient steam injectivity between the steam injection well and the production well for injection of the steam from the steam injection well to move hydrocarbons to the production well.

27. The method of claim 21, wherein the selected amount of heat provided from the first heater is reached after about one year of heating using the first heater.

28. The method of claim 21, wherein the first heater is turned off on or about the time injection of steam through the steam injection well is started.

29. The method of claim 21, wherein the initial vertical permeability in the hydrocarbon containing layer is at most about 300 millidarcy.

30. The method of claim 21, wherein the initial horizontal permeability in the hydrocarbon containing layer is at most about 1 darcy.

31. The method of claim 21, wherein the initial viscosity in the hydrocarbon containing layer is at least about 1 x 10^6 centipoise.

32. The method of claim 21, wherein the hydrocarbon containing layer has an initial permeability that is heterogenous.

33. The method of claim 21, wherein providing heat to the hydrocarbon containing layer from the first heater increases the steam injectivity in the layer.

34. A method of recovering energy from a subsurface hydrocarbon containing formation, comprising:

introducing an oxidizing fluid in a wellbore positioned in at least a first portion of a subsurface hydrocarbon containing formation, wherein at least a portion of the first portion of the subsurface hydrocarbon containing formation has been subjected to an in situ heat treatment process prior to introduction of the oxidizing fluid, and wherein the portion comprises a treatment area comprising elevated levels of coke substantially adjacent the wellbore;

increasing the pressure in the wellbore by introducing the oxidizing fluid under pressure such that the oxidizing fluid substantially permeates a majority of the treatment area and initiates a combustion process;

allowing heat from the combustion process to transfer to fluids in the treatment area;

decreasing the pressure in the wellbore such that heated fluids from the portion of the formation are conveyed into the wellbore; and

transferring heated fluids conveyed into the wellbore to the surface to a heat exchanger configured to collect thermal energy.

35. The method of claim 34, wherein the treatment area comprises residual hydrocarbons.

36. The method of claim 34, wherein the heated fluids comprise at least some heated oxidizing fluid.

37. The method of claim 34, wherein the heated fluids comprise at least some products from the combustion process.

38. The method of claim 34, further comprising transferring a heated heat transfer fluid from the heat exchanger to at least a second portion of the subsurface hydrocarbon containing formation.

39. The method of claim 38, wherein the heat transfer fluid comprises molten salt.

40. The method of claim 38, wherein the heat transfer fluid comprises molten metal.

41. The method of claim 38, wherein the heat transfer fluid comprises condensable hydrocarbons.

42. The method of claim 38, wherein the heat transfer fluid comprises thermally conductive gases.

43. The method of claim 42, wherein the thermally conductive gases comprise helium, carbon dioxide, and/or steam.

44. The method of claim 34, further comprising transferring a heated heat transfer fluid from the heat exchanger to at least a second portion of the subsurface hydrocarbon containing formation such that at least the second portion is heated using the heated heat transfer fluid.

45. The method of claim 34, further comprising creating a barrier, wherein the barrier is configured to inhibit oxidizing fluid introduced in the wellbore from being conveyed beyond the treatment area substantially adjacent the wellbore.

46. The method of claim 34, further comprising introducing a barrier forming fluid around the treatment area substantially adjacent the wellbore, wherein the barrier fluid is configured to solidify at or above a specified temperature range.

47. The method of claim 46, wherein the barrier forming fluid comprises a slurry.

48. The method of claim 46, wherein the barrier forming fluid comprises a slurry comprising solids and a low volatility solvent.

49. The method of claim 46, wherein the barrier forming fluid comprises ceramics, micas, and/or clays.

50. The method of claim 34, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore.

51. The method of claim 34, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a flow rate of the oxidizing fluid.

52. The method of claim 34, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting the change in pressure.

53. The method of claim 34, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a duration of the combustion process.

54. The method of claim 34, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by injecting steam in the wellbore.

55. The method of claim 34, further comprising conducting a cycling process, wherein the cycling process comprises repeatedly:

increasing the pressure in the wellbore using the oxidizing fluid; and

decreasing the pressure in the wellbore to remove at least some of the combustion products.

56. The method of claim 55, further comprising introducing sufficient oxidizing fluid in the wellbore such that the combustion process proceeds throughout the cycling process of the wellbore.

57. The method of claim 34, further comprising inhibiting heat loss in an overburden in at least the first portion of the subsurface hydrocarbon containing formation by insulating at least the portion of the wellbore in the overburden.

58. A method of recovering energy from a subsurface hydrocarbon containing formation, comprising:

introducing an oxidizing fluid in a wellbore positioned in at least a first portion of a subsurface hydrocarbon containing formation, wherein at least a portion of the first portion of the subsurface hydrocarbon containing formation has been subjected to an in situ heat treatment process prior to introduction of the oxidizing fluid, and wherein the portion comprises a treatment area comprising elevated levels of coke substantially adjacent the wellbore;

increasing the pressure in the wellbore by introducing the oxidizing fluid under pressure such that the oxidizing fluid substantially permeates a majority of the treatment area and initiates a combustion process;

allowing heat from the combustion process to transfer to fluids in the treatment area;

decreasing the pressure in the wellbore such that at least some heated fluids from the treatment area are conveyed into the wellbore; and

introducing a heat transfer fluid in the wellbore such that heat is transferred from the wellbore to the heat transfer fluid.

59. The method of claim 58, wherein the treatment area comprises residual hydrocarbons.

60. The method of claim 58, wherein the heated fluids comprise at least some heated oxidizing fluid.

61. The method of claim 58, wherein the heated fluids comprise at least some products from the combustion process.

62. The method of claim 58, further comprising transferring the heated heat transfer fluid from the wellbore to at least a second portion of the subsurface hydrocarbon containing formation.

63. The method of claim 58, further comprising transferring the heated heat transfer fluid from the wellbore to at least a second portion of the subsurface hydrocarbon containing formation such that at least the second portion is heated using the heated heat transfer fluid.

64. The method of claim 58, further comprising creating a barrier, wherein the barrier is configured to inhibit oxidizing fluid introduced in the wellbore from being conveyed beyond the treatment area substantially adjacent the wellbore.

65. The method of claim 58, further comprising introducing a barrier forming fluid around the treatment area substantially adjacent the wellbore, wherein the barrier fluid is configured to solidify at or above a specified temperature range.

66. The method of claim 65, wherein the barrier forming fluid comprises a slurry.

67. The method of claim 65, wherein the barrier forming fluid comprises a slurry comprising solids and a low volatility solvent.

68. The method of claim 65, wherein the barrier forming fluid comprises ceramics, micas, and/or clays.

69. The method of claim 58, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore.

70. The method of claim 58, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a flow rate of the oxidizing fluid.

71. The method of claim 58, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting the change in pressure.

72. The method of claim 58, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a duration of the combustion process.

73. The method of claim 58, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by injecting steam in the wellbore.

74. The method of claim 58, further comprising conducting a cycling process, wherein the cycling process comprises repeatedly:

increasing the pressure in the wellbore using the oxidizing fluid; and

decreasing the pressure in the wellbore to remove at least some of the combustion products.

75. The method of claim 74, further comprising introducing sufficient oxidizing fluid in the wellbore such that the combustion process proceeds throughout the cycling process of the wellbore.

76. The method of claim 58, further comprising inhibiting heat loss in an overburden in at least the first portion of the subsurface hydrocarbon containing formation by insulating at least the portion of the well bore in the overburden.

77. The method of claim 58, wherein the heat transfer fluid comprises molten salt.

78. The method of claim 58, wherein the heat transfer fluid comprises molten metal.

79. The method of claim 58, wherein the heat transfer fluid comprises condensable hydrocarbons.

80. The method of claim 58, wherein the heat transfer fluid comprises thermally conductive gases.

81. The method of claim 80, wherein the thermally conductive gases comprise helium, carbon dioxide, and/or steam.

82. An asphalt/bitumen composition, comprising:

at least 0.001 percent to about 50 percent by weight in situ heat treatment (ISHT) residue, wherein the residue has been obtained from products produced from in situ heat treatment of a subsurface hydrocarbon formation; and

at least 50 percent to about 99.999 percent by weight asphalt/bitumen.

83. A method of making asphalt/bitumen composition, comprising:

providing an in situ heat treatment (ISHT) residue produced from a subsurface hydrocarbon formation using an in situ heat treatment process; and

introducing at least a portion of the ISHT residue to asphalt/bitumen to form an ISHT residue/asphalt/bitumen composition, wherein the ISHT residue/asphalt/bitumen composition has at least 0.001 percent to about 50 percent by weight ISHT residue.

84. A method of heating a subsurface hydrocarbon containing formation, comprising:

providing heat flux per volume to a first portion of a subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more first heat sources positioned in the first portion; and

providing heat flux per volume to a second portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more second heat

sources positioned in the second portion, wherein the heat flux per volume provided by the two or more second heat sources is greater than the heat flux per volume provided by the two or more first heat sources, and wherein the second portion is positioned below the first portion.

85. The method of claim 84, further comprising pyrolyzing at least some of the hydrocarbons in the second portion.

86. The method of claim 84, further comprising:

pyrolyzing at least some of the hydrocarbons in the second portion; and

heating at least some of the first portion with at least some of the pyrolysis products from the second portion.

87. The method of claim 84, further comprising increasing the pressure in the formation to between about 2070 kPa and about 3450 kPa psi.

88. The method of claim 84, further comprising:

increasing the pressure in the formation to between about 2070 kPa and about 3450 kPa for a period of time; and

decreasing the pressure in the formation to between about 500 kPa and about 1000 kPa after the period of time.

89. The method of claim 84, further comprising:

increasing the pressure in the formation to between about 300 psi and about 500 psi for a period of 200 days to 600 days, 300 days to 500 days, or 350 days to 450 days; and

decreasing the pressure in the formation to between about 500 kPa and about 1000 kPa after the period of time.

90. The method of claim 84, wherein the heat flux per volume provided to the first portion is limited such that pyrolysis of hydrocarbons is inhibited in the first portion of the formation.

91. The method of claim 84, wherein the second portion of the formation comprises about a third of the formation positioned below an overburden.

92. The method of claim 84, wherein the first portion of the formation comprises about two thirds of the formation positioned below an overburden.

93. The method of claim 84, wherein the first portion of the formation comprises about two thirds of the formation positioned below an overburden, and wherein about 20 percent less heat flux per volume is provided to the first portion relative to the second portion.

94. The method of claim 84, wherein the first portion of the formation comprises about two thirds of the formation positioned below an overburden, and wherein about 20 percent less heat flux per volume is provided to the first portion relative to the second portion within the first five years of initially providing heat flux at least a portion of the formation.

95. The method of claim 84, further comprising providing heat flux per volume to a third portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more third heat sources positioned in the third portion, and wherein the third portion is positioned below the first portion and above the second portion.

96. The method of claim 84, further comprising providing heat flux per volume to a third portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more third heat sources positioned in the third portion, wherein the heat flux per volume provided by the two or more second heat sources is greater than the heat flux per volume provided by the two or more third heat sources, and wherein the third portion is positioned below the first portion and above the second portion.

97. The method of claim 84, further comprising providing heat flux per volume to a third portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more third heat sources positioned in the third portion, wherein the heat flux per volume provided by the two or more second heat sources is greater than the heat flux per volume provided by the two or more third heat sources, wherein the heat flux per volume provided by the two or more third heat sources is greater than the heat flux per volume provided by the two or more first heat sources, and wherein the third portion is positioned below the first portion and above the second portion.

98. The method of claim 84, wherein providing heat flux per volume to the first portion of the formation comprising providing heat flux per volume to a portion of a formation in the Nisku area.

99. The method of claim 84, further comprising positioning a production well in or adjacent to the second portion of the formation.

100. The method of claim 84, further comprising positioning a production well in or adjacent to the second portion of the formation, wherein spacing for heat sources adjacent to the production well are horizontally and/or vertically irregularly offset from the production well.

101. The method of claim 84, further comprising positioning a production well in or adjacent to the second portion of the formation such that hydrocarbons are removed from the second portion of the formation.

102. The method of claim 84, further comprising:

positioning a production well in or adjacent to the second portion of the formation; and

removing hydrocarbons from the second portion of the formation such that hydrocarbons from the first portion are conveyed towards the first portion of the formation.

103. The method of claim 84, further comprising:

positioning a producer well in or adjacent to the second portion of the formation;

removing hydrocarbons from the second portion of the formation such that hydrocarbons from the first portion are conveyed towards the first portion of the formation; and

pyrolyzing in the second portion at least some of the hydrocarbons conveyed from the first portion.

104. The method of claim 84, wherein the second portion of the formation comprises more second heat sources than the first portion comprises first heat sources.

105. The method of claim 84, wherein two or more of the second heat sources initiate heating before two or more of the first heat sources.

106. A system for heating a subsurface formation, comprising:

a heater wellbore located in a subsurface formation;

a heater comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and

a heater casing located in an overburden portion of the heater wellbore, which is located substantially in the overburden of the formation, the heater casing comprising an electrically nonconducting portion and an electrically conducting portion;

wherein the nonconducting portion begins at the surface of the formation, the conducting portion is located between the nonconducting portion and the heated portion of the heater, and the nonconducting portion extends to a depth that is at least about 150 m above the heated portion of the heater.

107. The system of claim 106, wherein the nonconducting portion is configured to inhibit induction of surface potentials from the lead-in portion of the heater in the overburden of the formation.

108. The system of claim 106, wherein the nonconducting portion is configured to inhibit linear current induction in the heater casing from the lead-in portion of the heater.

109. The system of claim 106, wherein the lead-in portion of the heater comprises a single-phase conductor.

110. The system of claim 106, wherein the nonconducting portion comprises fiberglass.

111. The system of claim 106, wherein the nonconducting portion extends to a depth that is greater than a distance between the heater wellbore and a closest additional heater wellbore in the formation.

112. A system for heating a subsurface formation, comprising:

a heater wellbore located in a subsurface formation;

a heater comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and

a heater casing located in an overburden portion of the heater wellbore, which is located substantially in the overburden of the formation, the heater casing comprising an electrically nonconducting portion and an electrically conducting portion;

wherein the nonconducting portion begins at the surface of the formation, the conducting portion is located between the nonconducting portion and the heated portion of the heater, and the nonconducting portion extends to a depth of at least about 10 m below the surface.

113. The system of claim 112, wherein the nonconducting portion is configured to inhibit induction of surface potentials from the lead-in portion of the heater in the overburden of the formation.

114. The system of claim 112, wherein the nonconducting portion is configured to inhibit linear current induction in the heater casing from the lead-in portion of the heater.

115. The system of claim 112, wherein the lead-in portion of the heater comprises a single-phase conductor.

116. The system of claim 112, wherein the nonconducting portion comprises fiberglass.

117. The system of claim 112, wherein the nonconducting portion extends to a depth that is greater than a distance between the heater wellbore and a closest additional heater wellbore in the formation.

118. A system for heating a subsurface formation, comprising:

a heater wellbore located in a subsurface formation;

a heater comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and

a heater casing located in an overburden portion of the heater wellbore, which is located substantially in the overburden of the formation, the heater casing comprising an electrically nonconducting portion and an electrically conducting portion;

wherein the nonconducting portion begins at the surface of the formation, the conducting portion is located between the nonconducting portion and the heated portion of the heater, and the nonconducting portion extends to at least to a depth that is at least below a surface moisture zone of the formation.

119. The system of claim 118, wherein the nonconducting portion is configured to inhibit induction of surface potentials from the lead-in portion of the heater in the overburden of the formation.

120. The system of claim 118, wherein the nonconducting portion is configured to inhibit linear current induction in the heater casing from the lead-in portion of the heater.

121. The system of claim 118, wherein the lead-in portion of the heater comprises a single-phase conductor.

122. The system of claim 118, wherein the nonconducting portion comprises fiberglass.

123. The system of claim 118, wherein the nonconducting portion extends to a depth that is greater than a distance between the heater wellbore and a closest additional heater wellbore in the formation.

124. A heating system for a subsurface formation, comprising:

a first tubular located in the subsurface formation;

a second tubular, wherein at least a portion of the first tubular is positioned in the second tubular; and

two or more elongated electrical conductors, wherein at least a portion of the electrical conductors are positioned between an outer surface of the first tubular and an inner surface of the second tubular;

wherein the electrical conductors are configured to provide heat to the subsurface formation when an electrical current is applied to the electrical conductors.

125. The heating system of claim 124, further comprising two or more spacers positioned between the first tubular and the second tubular.

126. The heating system of claim 124, further comprising two or more spacers positioned between the first tubular and the second tubular, wherein the spacers are configured to inhibit the elongated electrical conductors from contacting the inner surface of the second tubular.

127. The heating system of claim 124, wherein the elongated electrical conductors are configured to contact the inner surface of the second tubular.

128. A method of heating a subsurface formation, comprising:

introducing a molten salt into a first passageway of a conduit-in-conduit heater at a first location;

passing the molten salt through the conduit-in-conduit heater in the formation to a second location, wherein heat transfers from the molten salt to a treatment area during passage of the molten salt through the conduit-in-conduit heater; and

removing molten salt from the conduit-in-conduit heater at a second location spaced away from the first location.

129. The method of claim 128, wherein introducing the molten salt into the first passageway comprises introducing the molten salt into an inner conduit of the conduit-in-conduit heater.

130. The method of claim 128, wherein introducing the molten salt into the first passageway comprises introducing the molten salt into an inner conduit of the conduit-in-conduit heater, and passing the molten salt through a flow switcher to change the flow from the inner conduit to the annular region between the inner conduit and an outer conduit.

131. The method of claim 130, further comprising passing the molten salt through a second flow switcher to change the flow from the annular region between the inner conduit and the outer conduit to the inner conduit.

132. The method of claim 128, further comprising introducing a secondary heat transfer fluid into a second passageway of the conduit-in-conduit heater to ensure flowability of the molten salt in the first passageway.

133. The method of claim 132, further comprising eliminating or reducing flow of the secondary heat transfer fluid in the second passageway after a temperature of the conduit-in-conduit heater is sufficient to ensure flowability of the molten salt.

134. The method of claim 133, further comprising introducing a third heat transfer fluid into the first passageway of the conduit-in-conduit heater prior to introducing the molten salt to preheat the first passageway, and removing at least a portion of the third heat transfer fluid from the first passageway.

135. The method of claim 134, wherein removing at least a portion of the third heat transfer fluid comprises displacing the third heat transfer fluid with the molten salt.

136. A method of heating a subsurface formation, comprising:

introducing a secondary heat transfer fluid into a first passageway of a heater to preheat the heater;

introducing a primary heat transfer fluid into a second passageway of the heater; and

eliminating or reducing flow of the secondary heat transfer fluid into the first passageway after a temperature of the heater is sufficient to ensure flowability of the primary heat transfer fluid.

137. The method of claim 136, further comprising introducing a third heat transfer fluid into the second passageway of the heater prior to introducing the primary heat transfer fluid to preheat the second passageway, and removing at least a portion of the third heat transfer fluid from the second passageway.

138. The method of claim 137, wherein removing at least a portion of the third heat transfer fluid comprises displacing the third heat transfer fluid with the primary heat transfer fluid.

139. A system for heating a subsurface formation, comprising:

at least one fluid circulation system configured to provide a heat transfer fluid to a plurality of heaters in the formation; and

the plurality of heaters in the formation coupled to the circulation system, wherein at least one of the heaters comprises:

a first conduit;

a second conduit positioned in the first conduit; and

a first flow switcher configured to change the flow of the heat transfer fluid from the second conduit to the annular region between the first conduit and the second conduit.

140. The system of claim 139, wherein one or more of the heater are L-shaped heaters.

141. The system of claim 139, wherein the heat transfer fluid comprises a molten salt and the heat transfer fluid flows through the second conduit adjacent to at least a portion of the overburden, and wherein the heat transfer fluid flows through the annular region between the first conduit and the second conduit adjacent to at least a portion of a treatment area.

142. The system of claim 139, wherein the at least one fluid circulation system comprises a first fluid circulation system near a first side of a treatment area and a second fluid circulation system near a second side of the treatment area, and wherein the first circulation system provides the heat transfer fluid to entrances of a first set of heaters, and wherein the second fluid circulation system receives the heat transfer fluid from exits of the first set of heaters.

143. A method for heating a subsurface formation, comprising:

circulating a first heat transfer fluid through a heater positioned in the subsurface formation to raise a temperature of the heater to a temperature that ensures flowability of a second heat transfer fluid in the heater;

stopping circulation of the first heat transfer fluid through the heater; and

circulating the second heat transfer fluid through the heater positioned in the subsurface formation to raise the temperature of a heat treatment area adjacent to the heater.

144. The method of claim 143, wherein the heater comprises a conduit.

145. The method of claim 143, wherein the heater comprises a conduit-in-conduit heater, and wherein the first heat transfer fluid flows in a first passageway through the heater and wherein the second heat transfer fluid flows in a second passageway through the heater.

146. A method of heating a subsurface formation, comprising:

heating a first heat transfer fluid;

circulating the heated first heat transfer fluid through piping positioned in at least two of a plurality of wellbores using a fluid circulation system, wherein the plurality of wellbores are positioned in a formation;

heating at least a portion of a formation to a first temperature;

heating a second heat transfer fluid;

replacing the first heat transfer fluid positioned in the wellbores with the second heat transfer fluid; and

heating the portion of the formation to a second temperature, wherein the second temperature is higher than the first temperature.

147. The method of claim 146, further comprising:

recirculating the first heat transfer fluid through piping positioned in at least two of the wellbores using the fluid circulation system; and

heating the first heat transfer fluid using a part of the formation heated by the second heat transfer fluid.

148. The method of claim 146, further comprising:

recirculating the first heat transfer fluid through piping positioned in at least two of the wellbores using the fluid circulation system;

heating the first heat transfer fluid using a part of the formation heated by the second heat transfer fluid;

transferring the heated first heat transfer fluid from the formation to at least a portion of at least one additional formation; and

heating the portion of at least one of the additional formations using the heated first heat transfer fluid.

149. The method of claim 146, wherein the first heat transfer fluid and/or the second heat transfer fluid comprise molten salts.

150. The method of claim 146, wherein the first heat transfer fluid and the second heat transfer fluid comprise molten salts with different temperature ranges.

151. The method of claim 146, wherein the first heat transfer fluid comprises air, superheated steam, synthetic heat transfer fluid, or mixtures thereof.

152. A method of heating a subsurface formation, comprising:

circulating a first heat transfer fluid through piping positioned in at least two of a plurality of wellbores using a fluid circulation system, wherein the plurality of wellbores are positioned in a formation;

heating at least a portion of the first heat transfer fluid;

adding one or more salts to the heated portion of the first heat transfer fluid to form a heated salt solution comprising the first heat transfer fluid and the one or more salts;

heating at least a portion of a formation to a first temperature with the heated salt solution;

removing at least a portion of the first heat transfer fluid to form a second heat transfer fluid; and

heating the portion of the formation to a second temperature with the second heat transfer fluid, wherein the second temperature is higher than the first temperature.

153. The method of claim 152, wherein the one or more salts comprise one or more metals from Column 1 of the Periodic Table.

154. The method of claim 152, wherein the second heat transfer fluid is a molten salt.

155. The method of claim 152, wherein removing at least a portion of the first heat transfer fluid comprises adjusting a pressure of the circulation system to inhibit boiling of the first heat transfer fluid.

156. The method of claim 152, wherein adding one or more salts to the heated portion of the first heat transfer fluid comprises adjusting an amount of one or more of the salts to inhibit boiling of the salt solution.

157. The method of claim 152, further comprising cooling the second heat transfer fluid after heating the formation and adding a third heat transfer fluid to make another salt solution.

158. The method of claim 152, further comprising cooling the second heat transfer fluid after heating the formation, adding a third heat transfer fluid to make another salt solution, and heating another section of a formation with the third heat transfer fluid.

159. A system for heating a subsurface formation, comprising:

at least one fluid circulation system configured to provide a heat transfer fluid to a plurality of heaters in the formation; and

a plurality of heaters in the formation coupled to the circulation system, wherein at least one of the heaters comprises:

a first conduit;

a second conduit positioned in the first conduit; and

a first flow switcher configured to change fluid flow from the second conduit to flow through the annular region between the first conduit and the second conduit; and

wherein at least a portion of the first conduit is configured to be resistively heated when electrical current is applied to the portion of the first conduit, and wherein the resistive heat is configured to heat the heat transfer fluid to maintain flow of the heat transfer fluid in the heater.

160. The system of claim 159, wherein the portion of the first conduit configured to be resistively heated comprises an overburden portion positioned in the overburden.

161. A system for heating a subsurface formation, comprising:

at least one fluid circulation system configured to provide a heat transfer fluid to a plurality of heaters in the formation; and

a plurality of heaters in the formation coupled to the circulation system, wherein at least one of the heaters comprises:

a first conduit;

a second conduit positioned in the first conduit; and

a first flow switcher configured to change the flow of the heat transfer fluid from the second conduit to the annular region between the first conduit and the second conduit; and

wherein at least a portion of the second conduit is configured to be resistively heated when electrical current is applied to the portion, and wherein the resistive heat is configured to heat the heat transfer fluid to maintain flow of the heat transfer fluid in the heater.

162. The system of claim 161, wherein the portion of the second conduit configured to be resistively heated comprises an overburden portion positioned in the overburden.

163. A method for heating a subsurface formation, comprising:

applying heat from a plurality of heaters to at least a portion of the subsurface formation; and

allowing a portion of one or more of the heaters to move relative to the heaters respective wellhead using one or more sliding seals to accommodate thermal expansion of the heaters.

164. The method of claim 163, wherein applying heat from the plurality of heaters comprises flowing a heat transfer fluid through one or more heaters.

165. The method of claim 163, wherein the portion of a heater that moves relative to a wellhead is insulated.

166. The method of claim 163, further comprising fixing a position of a heater relative to a wellhead through which the heater passes after a significant change in a length of the heater due to thermal expansion ceases.

167. A method for heating a subsurface formation, comprising:

applying heat from a plurality of heaters to the subsurface formation; and

allowing a portion of one or more of the heaters to move relative to the heaters respective wellhead using one or more slip joints.

168. The method of claim 167, wherein at least a portion of at least one slip joint comprises at least one sliding seal, wherein the sliding seal is insulated from the applied heat.

169. The method of claim 167, wherein applying heat from the plurality of heaters comprises flowing a heat transfer fluid through one or more heaters.

170. The method of claim 167, wherein the portion of a heater that moves relative to a wellhead is insulated.

171. The method of claim 167, further comprising fixing a position of a heater relative to a wellhead through which the heater passes after a significant change in a length of the heater due to thermal expansion ceases.

172. A method for accommodating thermal expansion of a heater in a subsurface formation, comprising:

providing heat to a portion of the subsurface formation using a heated heater in the formation; and

lifting a portion of the heater out of the formation to accommodate thermal expansion of the heater.

173. The method of claim 172, wherein at least a portion of at least one slip joint comprises at least one sliding seal, wherein the sliding seal is insulated from the applied heat.

174. The method of claim 172, wherein applying heat from the heater comprises flowing a heat transfer fluid through the heater.

175. The method of claim 172, wherein the portion of the heater that moves out of a wellhead is insulated.

176. The method of claim 172, further comprising fixing a position of the heater relative to a wellhead through which the heater passes after a significant change in a length of the heater due to thermal expansion ceases.

177. A system for heating a subsurface formation, comprising:

a plurality of heaters positioned in the subsurface formation, the heaters configured to provide heat to at least a portion of the subsurface formation; and

at least one lifter coupled to a portion of a heater, the lifter configured to lift one or more portions of the heater out of the formation to accommodate thermal expansion of the heater.

178. The system of claim 177, wherein applying heat from the plurality of heaters comprises flowing a heat transfer fluid through one or more heaters.

179. The system of claim 177, wherein at least one lifter comprises a hydraulic lifter.

180. The system of claim 177, further comprising measuring a strain of the heater near at least one lifter, and controlling the amount of lift applied to the heater from the lifter based on the measured strain.

181. The system of claim 177, further comprising measuring a first hydraulic pressure of a lifter coupled to a heater before heating the heater, and controlling the hydraulic pressure of the lifter after heating is initiated to maintain the hydraulic pressure of the lifter at least close to the first hydraulic pressure.

182. The system of claim 177, further comprising fixing a position of a heater relative to a wellhead through which the heater passes after a significant change in a length of the heater due to thermal expansion ceases.

183. An in situ heat treatment system for producing hydrocarbons from a subsurface formation, comprising:

a plurality of wellbores in the formation;

at least one heater positioned in at least two of the wellbores; and

a self-regulating nuclear reactor configured to provide energy to at least one of the heaters to increase the temperature of at least a portion of the formation to temperatures that allow for hydrocarbon production from the formation;

wherein heat input to at least a portion of the formation over time at least approximately correlates to a rate of decay of the power from the self-regulating nuclear reactor.

184. The system of claim 183, wherein a spacing between at least a portion of the plurality of wellbores in the formation is at least partially correlated to the rate of decay of the power from the self-regulating nuclear reactor.

185. The system of claim 183, wherein the self-regulating nuclear reactor comprises a core, wherein the core comprises a powdered fissile metal hydride material.

186. The system of claim 183, wherein the power from the self-regulating nuclear reactor decays to about 1/E of an initial power of the self-regulating nuclear reactor in about 4 to 9 years.

187. The system of claim 183, wherein the self-regulating nuclear reactor initially provides to at least a portion of the wellbores a power output of about 300 watts/foot that decreases over time to about 120 watts/foot.

188. The system of claim 183, wherein the self-regulating nuclear reactor initially provides to at least a portion of the wellbores a power output of about 300 watts/foot that decreases over a predetermined time period to about 120 watts/foot.

189. The system of claim 183, wherein the self-regulating nuclear reactor initially provides to at least a portion of the wellbores a power output of about 300 watts/foot that decreases over a predetermined time period to about 120 watts/foot, wherein the predetermined time period ranges from about 4 to about 8 years.

190. The system of claim 183, wherein the self-regulating nuclear reactor initially provides to at least a portion of the wellbores a power output of about 300 watts/foot that decreases over a predetermined time period to about 120 watts/foot, wherein the predetermined time period ranges from about 5 to about 7 years.

191. The system of claim 183, wherein the self-regulating nuclear reactor is configured to provide energy to at least one of the heaters to increase the temperature of at least a portion of the formation to within a range of about 300 °C to about 400 °C.

192. The system of claim 183, wherein the self-regulating nuclear reactor is configured to provide energy to at least one of the heaters to increase the temperature of at least a portion of the formation to within a range of about 300 °C to about 400 °C within a predetermined time period, wherein the predetermined time period ranges from about 4 to about 8 years.

193. The system of claim 183, wherein the self-regulating nuclear reactor is configured to provide energy to at least one of the heaters to increase the temperature of at least a portion of the formation to within a range of about 300 °C to about 400 °C within a predetermined time period, wherein the predetermined time period ranges from about 5 to about 7 years.

194. The system of claim 183, wherein the spacing between at least a portion of the plurality of wellbores in the formation ranges between about 8 meters to about 11 meters.

195. The system of claim 183, wherein the spacing between at least a portion of the plurality of wellbores in the formation ranges between about 9 meters to about 10 meters.

196. The system of claim 183, wherein the spacing between at least a portion of the plurality of wellbores in the formation ranges between about 9.4 meters to about 9.8 meters.

197. The system of claim 183, wherein the self-regulating nuclear reactor is configured to provide thermal energy to at least one of the heaters using a heat transfer fluid.

198. The system of claim 183, wherein the self-regulating nuclear reactor is configured to provide thermal energy to at least one of the heaters using a heat transfer fluid, and wherein the heat transfer fluid comprises a molten salt.

199. A method of producing hydrocarbons from a subsurface formation, comprising:

providing energy to at least one heater to heat the temperature of the formation to temperatures that allow for hydrocarbon production from the formation using a self-regulating nuclear reactor, wherein the at least one heater is located in at least one of a plurality of heater wellbores located in the formation, and wherein at least one heater is located in at least one of the other heater wellbores; and

at least approximately correlating heat input to at least a portion of the formation over time to a rate of decay of the power from the self-regulating nuclear reactor.

200. The method of claim 199, further comprising at least partially correlating a spacing between at least a portion of the plurality of wellbores in the formation to the rate of decay of the power from the self-regulating nuclear reactor.

201. The method of claim 199, wherein the self-regulating nuclear reactor comprises a core, and wherein the core comprises a powdered fissile metal hydride material.

202. The method of claim 199, wherein the power from the self-regulating nuclear reactor decays to about 1/E of an initial power of the self-regulating nuclear reactor in about 4 to 9 years.

203. The method of claim 199, further comprising providing an initial power output using the self-regulating nuclear reactor of about 300 watts/foot that decreases over a predetermined time period to about 120 watts/foot to at least a portion of the wellbores.

204. The method of claim 199, further comprising providing an initial power output using the self-regulating nuclear reactor of about 300 watts/foot that decreases over a predetermined time period to about 120 watts/foot to at least a portion of the wellbores, wherein the predetermined time period ranges from about 4 to about 8 years.

205. The method of claim 199, further comprising providing energy to at least one of the heaters using the self-regulating nuclear reactor to increase the temperature of at least a portion of the formation to within a range of about 300 °C to about 400 °C.

206. The method of claim 199, further comprising providing energy to at least one of the heaters using the self-regulating nuclear reactor to increase the temperature of at least a portion of the formation to within a range of about 300 °C to about 400 °C within a predetermined time period, wherein the predetermined time period ranges from about 4 to about 8 years.

207. The method of claim 199, wherein the spacing between at least a portion of the plurality of wellbores in the formation ranges between about 8 meters to about 11 meters.

208. The method of claim 199, further comprising providing thermal energy to at least one of the heaters using a heat transfer fluid heated with the self-regulating nuclear reactor.

209. The method of claim 199, further comprising providing thermal energy to at least one of the heaters using a heat transfer fluid heated with the self-regulating nuclear reactor, wherein the heat transfer fluid comprises a molten salt.

210. An in situ heat treatment system for producing hydrocarbons from a subsurface formation, comprising:

a plurality of wellbores in the formation;

at least one heater positioned in at least two of the wellbores; and

a self-regulating nuclear reactor configured to provide energy to at least one of the heaters to heat the temperature of the formation to temperatures that allow for hydrocarbon production from the formation, wherein a temperature of the self-regulating nuclear reactor is controlled by controlling a pressure of hydrogen supplied to the self-regulating nuclear reactor, and wherein the pressure is regulated based upon formation conditions.

211. The system of claim 210, wherein the self-regulating nuclear reactor comprises a core, wherein the core comprises a powdered fissile metal hydride material.

212. The system of claim 210, wherein the temperature of the self-regulating nuclear reactor is reduced by introduction of a neutron-absorbing material.

213. The system of claim 210, wherein the temperature of the self-regulating nuclear reactor is reduced by introduction of a neutron-absorbing gas.

214. The system of claim 210, wherein the temperature of the self-regulating nuclear reactor is reduced by introduction of a neutron-absorbing gas, wherein the neutron-absorbing gas is $xenon^{135}$.

215. The system of claim 210, wherein the temperature of the self-regulating nuclear reactor is permanently reduced to ambient temperature upon introduction of a neutron-absorbing gas.

216. The system of claim 210, further comprising a system to convert nitrite to nitrate salts, or vice versa.

217. The system of claim 210, wherein the temperature of the self-regulating nuclear reactor is permanently reduced to ambient temperature upon introduction of a neutron-absorbing gas, wherein the neutron-absorbing gas is $xenon^{135}$.

218. The system of claim 210, wherein the self-regulating nuclear reactor sustains a temperature within a range of about 500 °C to about 650 °C.

219. The system of claim 210, wherein the self-regulating nuclear reactor is positioned underground in the formation.

220. The system of claim 210, wherein the self-regulating nuclear reactor is positioned underground in the formation below the overburden.

221. The system of claim 210, wherein the self-regulating nuclear reactor is positioned in or proximate to one or more tunnels.

222. The system of claim 210, wherein at least a one of the wellbores is u-shaped.

223. The system of claim 210, wherein at least a one of the wellbores is L-shaped.

224. The system of claim 210, further comprising at least a second self-regulating nuclear reactor, wherein the second self-regulating nuclear reactor is coupled to the self-regulating nuclear reactor after a first period of time such that the power output of the two coupled self-regulating nuclear reactors is at least as great as an initial output of the self-regulating nuclear reactor.

225. The system of claim 210, wherein the energy provided by the self-regulating nuclear reactor comprises a heat transfer fluid circulated by a circulation system through at least one of the heaters.

226. The system of claim 225, wherein the heat transfer fluid is a molten salt.

227. The system of claim 225, wherein the heat transfer fluid is a molten salt, and wherein the molten salt is molten at a temperature of the self-regulating nuclear reactor when it provides energy.

228. The system of claim 225, wherein the heat transfer fluid is a molten salt, wherein the molten salt does not decompose within a temperature range of the self-regulating nuclear reactor.

229. The system of claim 225, wherein the heat transfer fluid is a molten salt, and wherein the molten salt is a nitrite salt or a combination of nitrite salts.

230. The system of claim 225, wherein at least a portion of the heat transfer fluid circulates directly through the self-regulating nuclear reactor.

231. A method of producing hydrocarbons from a subsurface formation, comprising:

providing energy to at least one of heater to heat the temperature of the formation to temperatures that allow for hydrocarbon production from the formation using a self-regulating nuclear reactor, wherein the at least one heater is located in at least one of a plurality of heater wellbores located in the formation, and wherein at least one heater is located in at least one of the other heater wellbores;

controlling a temperature of the self-regulating nuclear reactor by controlling a pressure of hydrogen supplied to the self-regulating nuclear reactor; and

regulating the pressure of hydrogen supplied to the self-regulating nuclear reactor based upon formation conditions.

232. The method of claim 231, wherein the self-regulating nuclear reactor comprises a core, and wherein the core comprises a powdered fissile metal hydride material.

233. The method of claim 231, further comprising reducing the temperature of the self-regulating nuclear reactor by introducing a neutron-absorbing material.

234. The method of claim 231, further comprising reducing the temperature of the self-regulating nuclear reactor by introducing a neutron-absorbing gas.

235. The method of claim 231, further comprising reducing the temperature of the self-regulating nuclear reactor by introducing a neutron-absorbing gas, wherein the neutron-absorbing gas is $xenon^{135}$.

236. The method of claim 231, further comprising reducing the temperature of the self-regulating nuclear reactor to ambient temperature by introducing a neutron-absorbing gas.

237. The method of claim 231, further comprising sustaining the self-regulating nuclear reactor at a temperature within a range of about 500 °C to about 650 °C.

238. The method of claim 231, further comprising positioning the self-regulating nuclear reactor underground in the formation.

239. The method of claim 231, further comprising positioning the self-regulating nuclear reactor underground below the overburden in the formation.

240. The method of claim 231, further comprising positioning the self-regulating nuclear reactor in or proximate to one or more tunnels.

241. The method of claim 231, further comprising coupling at least a second self-regulating nuclear reactor to the self-regulating nuclear reactor after a first period of time such that the power output of the two coupled self-regulating nuclear reactors is at least as great as an initial output of the self-regulating nuclear reactor.

242. The method of claim 231, further comprising:

heating a heat transfer fluid using the self-regulating nuclear reactor; and

circulating the heat transfer fluid through at least one of the heaters using a circulation system.

243. The method of claim 242, wherein the heat transfer fluid is a molten salt.

244. The method of claim 242, wherein the heat transfer fluid is a molten salt, and wherein the molten salt does not decompose within a temperature range of the self-regulating nuclear reactor.

245. The method of claim 242, wherein the heat transfer fluid is a molten salt, and wherein the molten salt comprises nitrite salt.

246. The method of claim 242, wherein at least a portion of the heat transfer fluid circulates directly through the self-regulating nuclear reactor.

247. A system for forming a subsurface wellbore, comprising:

a rack and pinion system comprising a chuck drive system, wherein the chuck drive system is configured to operate a drilling string; and

an automatic position control system comprising at least one measurement sensor coupled to the rack and pinion system, wherein the automatic position control system is configured to control the rack and pinion system to determine a position of the drilling string.

248. The system of claim 247, wherein the chuck drive system is configured to hold a tubular.

249. The system of claim 247, wherein the chuck drive system is configured to hold a tubular, and the tubular comprises one or more heaters.

250. The system of claim 247, wherein the chuck drive system is configured to hold a tubular comprising one or more heaters, and at least one of the heaters comprises one or more magnetic ranging sensors.

251. The system of claim 247, wherein the chuck drive system is configured to hold a tubular comprising one or more heaters, and at least one of the heaters comprises one or more non-rotating sensors.

252. The system of claim 247, wherein the automatic position control system is configured to be continuously or semi-continuously calibrated during drilling.

253. The system of claim 247, wherein the automatic position control system comprises one or more rotary steerable systems.

254. The system of claim 247, wherein the automatic position control system comprises one or more dual motor rotary steerable systems.

255. The system of claim 247, wherein the automatic position control system comprises one or more hole measurement systems.

256. The system of claim 247, wherein the automatic position control system comprises one or more hole measurement systems and wherein at least one hole measurement system comprises one or more canted accelerometers.

257. A method for forming a subsurface wellbore, comprising:

receiving position data about a tubular from at least one measurement sensor coupled to an automatic position control system; and

controlling a direction of the tubular in a subsurface formation using a rack and pinion system based on the position data from the measurement sensor.

258. The method of claim 257, wherein the measurement sensor comprises one or more canted accelerometers.

259. The method of claim 257, wherein the position data is obtainable in the presence of magnetic interference sources.

260. The method of claim 257, wherein the position data comprises relative rotational data of the tubular shaft.

261. A system for forming a subsurface wellbore, comprising:

a bottom drive system configured to couple to an existing tubular of a drilling string at least partially in the subsurface wellbore and to control a drilling operation in the wellbore, the bottom drive system comprising a circulating sleeve configured to accept a new tubular during the drilling operation; and

a top drive system configured to couple with the new tubular and to assume control of the drilling operation when the new tubular is coupled to the existing tubular.

262. The system of claim 261, wherein the bottom drive system is configured to move at least partially up to the top of the new tubular while the top drive system is controlling the drilling operation and to assume control of the drilling operation from the top drive system.

263. The system of claim 261, further comprising a tubular handling system configured to position the new tubular for coupling with the top drive system.

264. The system of claim 261, wherein the top drive system comprises a circulating sleeve, and the circulating sleeve of the bottom drive system is configured to receive fluid from the circulating sleeve of the top drive system.

265. The system of claim 261, wherein the circulating sleeve is configured to maintain a pressure up to pressures of about 13.8 MPa.

266. A method for adding a new tubular to a drilling string, comprising:

coupling a top end of the new tubular to a top drive system;

positioning a bottom end of the new tubular in an opening of a circulating sleeve of a bottom drive system while the bottom drive system controls a drilling operation;

while the drilling operation continues, coupling the new tubular to an existing tubular to form a coupled tubular;

transferring control of the drilling operation from the bottom drive system to the top drive system;

while the drilling operation continues, moving the bottom drive system up the coupled tubular towards the top drive system;

while the drilling operation continues, coupling the bottom drive system to a top portion of the coupled tubular;

transferring control of the drilling operation from the top drive system to the bottom drive system; and

disconnecting the top drive system from the coupled tubular.

267. The method of claim 266, further comprising providing fluid to the bottom drive system from the circulating sleeve of the bottom drive system; and once the new tubular is positioned in the opening of the circulation sleeve of a bottom drive system, providing fluid from a circulating sleeve of the top drive system to the bottom drive system.

268. The method of claim 266, further comprising maintaining a pressure up to about 13.8 MPa in the circulating sleeve of the bottom drive system.

269. The method of claim 266, wherein coupling the new tubular to the existing tubular comprises applying sufficient pressure to pressure-fit the tubulars together.

270. A method for treating a hydrocarbon containing formation, comprising:

providing heat to a first portion of the formation using a heater, wherein the heating section of the heater is at least partially located in a substantially horizontal or inclined portion of a wellbore and is located in or proximate to a hydrocarbon containing layer of the formation, and wherein the heating section has a length that is at most ½ the length of the horizontal or inclined portion of the wellbore; and

moving at least a portion of the heating section in the wellbore such that heat is provided to a second portion of the formation, wherein the second portion is horizontally displaced from the first portion of the formation.

271. The method of claim 270, wherein the wellbore is a u-shaped wellbore.

272. The method of claim 270, wherein the wellbore is an L-shaped wellbore.

273. The method of claim 270, further comprising moving the heating section in the wellbore such that the heating section provides heat to a third portion of the formation, wherein the third portion is horizontally displaced from the first and second portions of the formation.

274. The method of claim 270, wherein the second portion is adjacent to the first portion.

275. The method of claim 270, wherein the heating section is moved from heating the first portion to heating the second portion after a selected time period of heating of the first portion.

276. The method of claim 270, wherein the heating section is moved from heating the first portion to heating the second portion after at least some hydrocarbons in the first portion are mobilized.

277. The method of claim 270, wherein the heating section is moved from heating the first portion to heating the second portion after at least some hydrocarbons in the first portion are pyrolyzed.

278. The method of claim 270, further comprising moving the heating section by moving at least a portion of the heater in the wellbore.

279. The method of claim 270, further comprising moving the heating section by pulling at least a portion of the heater through the wellbore.

280. The method of claim 270, wherein the wellbore is a u-shaped wellbore, the method further comprising moving the heating section by moving at least a portion of the heater through the wellbore from at or near one end of the wellbore to at or near the other end of the wellbore.

281. The method of claim 270, further comprising mobilizing at least some hydrocarbons in the first portion, and producing at least some of the mobilized hydrocarbons.

282. The method of claim 270, further comprising pyrolyzing at least some hydrocarbons in the first portion, and producing at least some of the pyrolyzed hydrocarbons.

283. The method of claim 270, wherein the heating section has a length that is at most ¼ the length of the horizontal or inclined portion of the wellbore.

284. The method of claim 270, wherein the heating section has a length that is at most 1/5 the length of the horizontal or inclined portion of the wellbore.

285. The method of claim 270, wherein the heater comprises an electrical resistance heater.

286. The method of claim 270, wherein the heater comprises an oxidation heater.

287. The method of claim 270, wherein the heater comprises a circulating fluid heater.

288. The method of claim 270, further comprising providing steam to at least a portion of the formation.

289. A method for treating a hydrocarbon containing formation, comprising:

providing heat to a first portion of the formation using a first heater, wherein the heating section of the first heater is at least partially located in a substantially horizontal or inclined portion of a wellbore and is located in or proximate to a hydrocarbon containing layer of the formation, and wherein the heating section of the first heater has a length that is at most ½ the length of the horizontal or inclined portion of the wellbore;

providing heat to a second portion of the formation using a second heater, wherein the heating section of the second heater is at least partially located in a substantially horizontal or inclined portion of the wellbore and is located in or proximate to the hydrocarbon containing layer of the formation, and wherein the heating section of the second heater has a length that is at most ½ the length of the horizontal or inclined portion of the wellbore;

wherein the first portion and the second portion of the formation are horizontally displaced from each other in the formation; and

moving at least a portion of the heating section of the first heater in the wellbore such that heat is provided to a third portion of the formation, wherein the third portion is horizontally displaced from the first portion of the formation and the second portion of the formation, and wherein the third portion is closer to the first portion than the second portion.

290. The method of claim 289, further comprising moving at least a portion of the heating section of the second heater in the wellbore such that heat is provided to a fourth portion of the formation, wherein the fourth portion is horizontally displaced from the first portion of the formation and the second portion of the formation, and wherein the fourth portion is closer to the second portion than the first portion.

291. The method of claim 290, wherein the fourth portion is substantially the same distance from the second portion as the third portion is from the first portion.

292. The method of claim 289, wherein the wellbore is a u-shaped wellbore.

293. The method of claim 289, wherein the wellbore is an L-shaped wellbore.

294. The method of claim 289, wherein the second portion is adjacent to the first portion.

295. The method of claim 289, wherein the heating section of the first heater is moved from heating the first portion to heating the third portion after at least some hydrocarbons in the first portion are mobilized.

296. The method of claim 289, wherein the heating section of the first heater is moved from heating the first portion to heating the third portion after at least some hydrocarbons in the first portion are pyrolyzed.

297. The method of claim 289, further comprising moving the heating section of the first heater by moving at least a portion of the heater in the wellbore.

298. The method of claim 289, further comprising moving the heating section of the first heater by pulling at least a portion of the heater through the wellbore.

299. The method of claim 289, further comprising mobilizing at least some hydrocarbons in the first portion, and producing at least some of the mobilized hydrocarbons.

300. The method of claim 289, further comprising pyrolyzing at least some hydrocarbons in the first portion, and producing at least some of the pyrolyzed hydrocarbons.

301. The method of claim 289, further comprising providing steam to at least a portion of the formation.

302. The method of claim 289, wherein the first portion is located substantially adjacent the second portion such that at least some of the heating provided in the portions substantially overlaps.

303. A heater, comprising:

a conduit;

three insulated electrical conductors located in the conduit, at least one of the three insulated conductors comprising an electrical conductor at least partially surrounded by an insulation layer and an electrically conductive sheath at least partially surrounding the insulation layer; and

one or more layers of electrical insulation at least partially surrounding the three insulated electrical conductors in the conduit, the one or more layers of electrical insulation being configured to electrically isolate the insulated electrical conductors from the conduit.

304. The heater of claim 303, wherein one or more of the layers of electrical insulation comprises one or more layers of tape comprising ceramic fibers.

305. The heater of claim 303, wherein one or more of the layers of electrical insulation comprises high temperature ceramic fiber rope.

306. The heater of claim 303, wherein one or more of the layers of electrical insulation are configured to withstand operating temperatures of at least about 750 °C.

307. The heater of claim 303, wherein the heater has a length of at least about 100 m.

308. The heater of claim 303, wherein the heater is configured to operate at a voltage of at least about 4000 V.

309. The heater of claim 303, wherein the electrically conductive sheath comprises corrosion resistant material.

310. The heater of claim 303, wherein the conduit comprises corrosion resistant material.

311. A method for making a heater for a subsurface formation, comprising:

at least partially covering three insulated electrical conductors with one or more layers of electrical insulation, at least one of the insulated electrical conductors comprising:

an electrical conductor;

an insulation layer at least partially surrounding the electrical conductor; and

an electrically conductive sheath at least partially surrounding the insulation layer; and

forming a conduit around the one or more layers of electrical insulation and the three insulated electrical conductors.

312. The method of claim 311, further comprising installing the heater in an opening in the subsurface formation.

313. The method of claim 311, further comprising installing the heater in an opening in the subsurface formation, and energizing the heater to provide at least some heat to the subsurface formation.

314. The method of claim 311, further comprising spooling the conduit on a reel.

315. The method of claim 311, wherein forming the conduit around the one or more layers of electrical insulation and the three insulated electrical conductors comprises bending a plate around the one or more layers of electrical insulation and the three insulated electrical conductors and welding the seam.

316. The method of claim 311, wherein at least one insulated conductor comprises one or more heater sections configured to provide heat to heat a subsurface formation adjacent to the heater sections, and one or more other sections configured to transport electricity to the heater sections with relatively small heat losses.

317. A method for treating a subsurface formation using an electric heater, comprising:

providing electricity to the electric heater positioned in an opening in the subsurface formation, the electric heater comprising:

a conduit;

three insulated electrical conductors located in the conduit, at least one of the three insulated conductors comprising an electrical conductor at least partially surrounded by an insulation layer and an electrically conductive sheath at least partially surrounding the insulation layer; and

one or more layers of electrical insulation at least partially surrounding the three insulated electrical conductors in the conduit, the one or more layers of electrical insulation being configured to electrically isolate the insulated electrical conductors from the conduit; and

resistively heating one or more sections of one or more of the three electrical conductors; and

heating the subsurface formation adjacent to the conduit.

318. The method of claim 317, further comprising heating the subsurface formation such that at least some hydrocarbons in the formation are mobilized.

319. The method of claim 317, further comprising heating the subsurface formation such that at least some hydrocarbons in the formation are pyrolyzed.

320. The method of claim 317, further comprising heating the subsurface formation such that at least some hydrocarbons in the formation are mobilized, and producing at least some of the mobilized hydrocarbons through a production well.

321. The method of claim 317, further comprising heating the subsurface formation such that at least some hydrocarbons in the formation are pyrolyzed, and producing at least some of the pyrolyzed hydrocarbons through a production well.

322. The method of claim 317, further comprising heating the subsurface formation by providing time-varying electrical current to the electric heater.

323. A method for making a coiled insulated conductor heater configured to heat a subsurface formation, comprising:

pushing the insulated conductor heater longitudinally inside a flexible conduit using pressure, wherein one or more cups are coupled to the outside of the insulated conductor heater, the cups being configured to maintain at least some pressure inside at least a portion of the flexible conduit as the insulated conductor heater is pushed inside the flexible conduit; and

coiling the flexible conduit and the insulated conductor heater onto a coiled tubing rig.

324. The method of claim 323, wherein the cups are flexible cups.

325. The method of claim 323, wherein the cups comprise elastomeric cups.

326. The method of claim 323, wherein the cups provide little or no mechanical resistance to the movement of the insulated conductor heater inside the flexible conduit.

327. The method of claim 323, wherein one or more of the cups are configured to at least partially burn or melt after the insulated conductor heater is energized and the temperature of the insulated conductor heater increases.

328. The method of claim 323, wherein the insulated conductor heater is at least about 10 m in length.

329. A coiled insulated conductor heater system configured to heat a subsurface formation, comprising:

a flexible conduit;

an insulated conductor heater located longitudinally inside the flexible conduit; and

one or more cups coupled to the outside of the insulated conductor heater, the cups being configured to maintain pressure inside the flexible conduit;

wherein the flexible conduit and the insulated conductor heater are configured to be coiled onto a coiled tubing rig.

330. The system of claim 329, wherein the cups are flexible cups.

331. The system of claim 329, wherein the cups comprise elastomeric cups.

332. The system of claim 329, wherein the cups provide little or no mechanical resistance to the movement of the insulated conductor heater inside the flexible conduit.

333. The system of claim 329, wherein the cups are configured to burn up when the insulated conductor heater is energized and the temperature of the insulated conductor heater increases.

334. The system of claim 329, wherein the insulated conductor heater is at least about 10 m in length.

335. A method for installing a horizontal or inclined subsurface insulated conductor heater, comprising:

installing a flexible conduit and an insulated conductor heater into a subsurface wellbore by uncoiling the flexible conduit and the insulated conductor heater from a coiled tubing rig, wherein the insulated conductor heater is located longitudinally inside the flexible conduit, and one or more cups are coupled to the outside of the insulated conductor heater, the cups being configured to maintain pressure inside the flexible conduit; and

removing the flexible conduit from the subsurface wellbore with the coiled tubing rig while leaving the insulated conductor heater installed in the subsurface wellbore.

336. The method of claim 335, wherein the cups are flexible cups.

337. The method of claim 335, wherein the cups comprise elastomeric cups.

338. The method of claim 335, wherein the cups provide little or no mechanical resistance to the movement of the insulated conductor heater inside the flexible conduit.

339. The method of claim 335, wherein one or more of the cups are configured to at least partially burn or melt when the insulated conductor heater is energized and the temperature of the insulated conductor heater increases.

340. The method of claim 335, further comprising placing a guide string on an end of the flexible conduit and insulated conductor heater assembly.

341. The method of claim 335, further comprising:

placing a guide string on an end of the flexible conduit and insulated conductor heater assembly; and

using the guide string to guide the installation of the flexible conduit and insulated conductor heater assembly into the subsurface wellbore.

342. The method of claim 335, wherein the insulated conductor heater is at least about 10 m in length.

343. The method of claim 335, further comprising stopping removal of the flexible conduit at a bend in the subsurface wellbore, and pumping plugging material through the flexible conduit to the bend in the subsurface wellbore, wherein the plugging material is configured to plug the subsurface wellbore around the insulated conductor heater at the bend in the subsurface wellbore.

344. The method of claim 335, wherein the insulated conductor heater is placed in a hydrocarbon containing layer of the subsurface formation.

345. A method for heating a subsurface formation, comprising:

providing heat from an insulated conductor heater to at least a portion of the formation, wherein the insulated conductor heater has been installed in the formation by:

installing a flexible conduit and the insulated conductor heater into a subsurface wellbore by uncoiling the flexible conduit and the insulated conductor heater from a coiled tubing rig, wherein the insulated conductor heater is located longitudinally inside the flexible conduit, and one or more cups are coupled to the outside of the insulated conductor heater, the cups being configured to maintain pressure inside the flexible conduit; and

removing the flexible conduit from the subsurface wellbore with the coiled tubing rig while leaving the insulated conductor heater installed in the subsurface wellbore.

346. The method of claim 345, wherein the cups are flexible cups.

347. The method of claim 345, wherein the cups comprise elastomeric cups.

348. The method of claim 345, wherein the cups provide little or no mechanical resistance to the movement of the insulated conductor heater inside the flexible conduit.

349. The method of claim 345, further comprising at least partially burning or melting one or more of the cups.

350. The method of claim 345, wherein the insulated conductor heater is at least about 10 m in length.

351. The method of claim 345, further comprising mobilizing at least some hydrocarbons in the formation with the provided heat, and producing at least some of the mobilized hydrocarbons from the formation.

352. The method of claim 345, further comprising pyrolyzing at least some hydrocarbons in the formation with the provided heat, and producing at least some of the pyrolyzed hydrocarbons from the formation.

353. A method of positioning wellbores for forming a double barrier for at least a portion of a treatment area, comprising:

forming a plurality of first barrier wells in the formation for the first barrier, wherein a substantially constant spacing separates adjacent first barrier wells;

analyzing the formation to determine the principal fracture direction of at least one layer of the formation;

determining an offset distance of the second barrier wells relative to the first barrier wells based on the principal fracture direction to limit a maximum separation distance between a closest barrier well and a theoretical fracture extending between the first barrier and the second barrier along the principal fracture direction to a distance of less than one half of the spacing that separates adjacent first barrier wells; and

forming a plurality of second barrier wells in the formation for the second barrier to a side of the first barrier wells by a substantially constant separation distance, wherein the second barrier wells are offset from the first barrier wells by a distance that is at least substantially the same as the offset distance.

354. The method of claim 353, wherein the first barrier wells are freeze wells.

355. The method of claim 353, wherein the second barrier wells are freeze wells.

356. The method of claim 353, further comprising forming the first barrier.

357. The method of claim 353, further comprising forming the second barrier.

358. The method of claim 353, wherein the offset distance is chosen to limit the maximum separation distance between the closest barrier well and the theoretical fracture extending between the first barrier and the second barrier along the principal fracture direction to a distance of about one fourth of the spacing that separates adjacent first barrier wells.

359. A method of positioning wellbores for forming a double barrier for at least a portion of a treatment area, comprising:

forming a plurality of first barrier wells in the formation for the first barrier, wherein a substantially constant spacing separates adjacent first barrier wells;

analyzing the formation to determine the principal direction of water flow in at least one layer of the formation;

determining an offset distance of the second barrier wells relative to the first barrier wells based on the principal direction of water flow in at least one layer to limit a maximum separation distance between a closest barrier well and a theoretical breach extending from the first barrier to the second barrier along the principal direction of water flow to a distance of less than one half of the spacing that separates adjacent first barrier wells; and

forming a plurality of second barrier wells in the formation for the second barrier to a side of the first barrier wells by a substantially constant separation distance, wherein the second

barrier wells are offset from the first barrier wells by a distance that is at least substantially the same as the offset distance.

360. The method of claim 359, wherein the first barrier wells are freeze wells.

361. The method of claim 359, wherein the second barrier wells are freeze wells.

362. The method of claim 359, further comprising forming the first barrier.

363. The method of claim 359, further comprising forming the second barrier.

364. The method of claim 359, wherein the offset distance is chosen to limit the maximum separation distance between the closest barrier well and the theoretical breach extending from the first barrier to the second barrier along the principal direction of water flow to a distance of about one fourth of the spacing that separates adjacent first barrier wells.

365. A method of treating a hydrocarbon formation, comprising:

providing heat to the hydrocarbon formation from a plurality of heaters;

allowing the heat to transfer from the heaters such that at least a section the formation reaches a selected temperature; the section comprising hydrocarbons having an API gravity below 10°;

providing a solution comprising water to the section, wherein a temperature of the solution is at least 250 °C;

maintaining a pressure of the formation such that the water remains a liquid at 250 °C;

contacting at least a some of the hydrocarbons in the section having an API gravity below 10° with the solution to produce hydrocarbon fluids; and

mobilizing the hydrocarbon fluids in the section, wherein the hydrocarbon fluids comprise hydrocarbons having an API gravity of at least 10°.

366. The method of claim 365, wherein the hydrocarbons comprise bitumen.

367. The method of claim 365, wherein the section comprises kerogen and heating the kerogen produces heavy hydrocarbons.

368. The method of claim 365, wherein the section comprises kerogen and heating the kerogen produces bitumen.

369. The method of claim 365, wherein maintaining a pressure comprises controlling the pressure of the formation in a range from 5,000 kPa to 15,000 kPa.

370. The method of claim 365, wherein the temperature of the solution ranges from 250 ° and 350 °C and the pressure is maintained from 5,000 kPa to 15,000 kPa.

371. The method of claim 365, wherein the viscosity of the hydrocarbon fluids is at least 100 centipoise at 15 °C.

372. The method of claim 365, further comprising producing at least a portion of the mobilized hydrocarbon fluids.

373. The method of claim 365, wherein the solution further comprises one or more aromatic compounds.

374. The method of claim 365, wherein the solution further comprises one or more phenol compounds.

375. The method of claim 365, wherein the solution further comprises one or more creosol compounds.

376. A method of treating an oil shale formation, comprising:

providing heat to the oil shale formation from a plurality of heaters, at least a portion of the oil shale formation comprising kerogen;

allowing the heat to transfer from the heaters such that at least some of the kerogen in the section is transformed to hydrocarbons comprising bitumen;

providing a solution comprising water to the section, wherein a temperature of the solution is at least 250 °C;

maintaining a pressure of the formation such that the water remains a liquid at 250 °C;

contacting at least a some of the hydrocarbons comprising bitumen with the solution; and

mobilizing hydrocarbon fluids in the section, wherein the hydrocarbon fluids comprise hydrocarbons having a viscosity less than a viscosity of bitumen.

377. A method of treating a hydrocarbon formation, comprising:

providing heat to the hydrocarbon formation from a plurality of heaters, at least one of the heaters being located in a heater well in the section;

allowing the heat to transfer from the heaters such that at least a section the formation reaches a selected temperature;

providing a solution comprising water to the section to the heater well, the heater well comprising hydrocarbons having an API gravity below 10° and wherein a temperature of the solution is at least 250 °C;

maintaining a pressure of the heater well such that the water remains a liquid at 250 °C;

contacting at least a some of the hydrocarbons in the heater well having an API gravity below 10° with the solution to produce hydrocarbon fluids; and

mobilizing the hydrocarbon fluids in the section, wherein the hydrocarbon fluids comprise hydrocarbons having an API gravity of at least 10°.

378. A system for treating a subsurface formation, comprising:

a plurality of conduits at least partially located in a portion of a hydrocarbon containing formation, wherein at least part of two of the conduits are aligned in relation to each other such that electrical current will flow from a first conduit to a second conduit, and wherein the first and

second conduits comprise electrically conductive material and at least one of the first and second conduits is perforated or configured to be perforated; and

a power supply coupled to the first and second conduits, the power supply configured to electrically excite at least one of the conductive sections such that current flows between the first conduit and the second conduit in the formation and heats at least a portion of the formation between the two conduits.

379. The system of claim 378, wherein at least a portion of the first conduit and at least a portion of the second conduit are substantially horizontal or inclined in the formation.

380. The system of claim 378, wherein at least a portion of the first conduit and at least a portion of the second conduit are substantially parallel to each other.

381. The system of claim 378, wherein at least a portion of the first and second conduits are perforated.

382. The system of claim 378, wherein the electrically conductive material is copper.

383. The system of claim 378, wherein at least one of the first and second conduits is a pipe.

384. The system of claim 378, wherein at least one of the first and second conduits comprises heat treated copper.

385. The system of claim 378, wherein at least one of the first and second conduits comprises a first layer comprising carbon steel and a second layer comprising copper, and at least a portion of the second layer substantially surrounds or partially surrounds a portion of the first layer.

386. The system of claim 378, wherein at least one of the first and second conduits comprises a portion positioned in an overburden section and the portion comprises one or more ferromagnetic materials.

387. The system of claim 378, wherein at least one of the first and second conduits comprises a portion positioned in an overburden section and the portion comprises at least 15% by weight manganese.

388. The system of claim 378, wherein at least one of the first and second conduits comprises a portion positioned in an overburden section and the portion comprises one or more ferromagnetic materials, and one or more of the ferromagnetic materials comprises at least 10% by weight manganese.

389. The system of claim 378, wherein at least one of the first and second conduits comprises a portion positioned in an overburden section and the portion comprises one or more ferromagnetic materials, and one or more of the ferromagnetic materials comprises at least 10 percent by weight manganese, at least 5 percent by weight carbon, and at least 1 percent by weight chromium.

390. The system of claim 378, wherein at least one of the first and second conduits is located in a wellbore comprising one or more electrical insulators.

391. The system of claim 378, wherein the first conduit is located in a first wellbore and the second conduit is located in a second wellbore.

392. The system of claim 378, further comprising a fluid injection system configured to inject fluid through at least some of the perforations and into the formation.

393. The system of claim 392, wherein the fluid comprises a drive fluid.

394. The system of claim 392, wherein the fluid comprises a foaming composition.

395. A method for treating a subsurface formation, comprising:

providing electrical current to a first conduit in a section of the formation such that electrical current flows from the first conduit to a second conduit in the section of the formation, the electrical current flowing through at least a portion of the formation to heat at least part of the formation; and

injecting a drive fluid through perforations in the first conduit such that the drive fluid flows through the perforations and moves formation fluids towards the second conduit and/or another section of the formation.

396. The method of claim 395, further comprising positioning the first conduit in the section of the formation, wherein the first conduit is oriented substantially horizontally or at an incline and wherein the first conduit comprises electrically conductive material.

397. The method of claim 395, further comprising positioning the second conduit in the section of the formation, wherein the second conduit is aligned in relation to the first conduit such that electrical current flows between the first and second conduits.

398. The method of claim 395, further comprising electrically exciting electrically conductive material in the first and/or second conduit to create the electrical current flow.

399. The method of claim 395, further comprising creating increased fluid injectivity in at least a portion of the section between the first and second conduits.

400. The method of claim 395, further comprising perforating at least a portion of the first conduit and/or the second conduit.

401. The method of claim 395, further comprising producing at least a portion of the mobilized formation fluids from the formation.

402. The method of claim 395, further comprising perforating at least a portion of the first or second conduit, and producing at least a portion of the mobilized formation fluids from the perforated first or second conduit.

403. The method of claim 395, wherein the first conduit comprises a conductive portion that is at least 10 meters from a conductive portion of the second conduit.

404. The method of claim 395, wherein the drive fluid is steam and/or water.

405. The method of claim 395, further comprising injecting a foaming composition, and injecting a pressurizing fluid at a rate sufficient to foam the foaming composition.

406. The method of claim 395, further comprising injecting a pre-foamed composition.

407. The method of claim 395, further comprising injecting a foaming composition, wherein the foaming composition comprises a surfactant.

408. The method of claim 395, wherein at least a portion of the first conduit is positioned in a shale layer of the formation.

409. The method of claim 395, wherein the first conduit is located in a first wellbore and the second conduit is located in a second wellbore.

410. A system for treating a subsurface formation, comprising:

a wellbore at least partially located in a hydrocarbon containing formation, the wellbore comprising a substantially vertical portion and at least two substantially horizontal or inclined portions coupled to the vertical portion;

a first conductor at least partially positioned in a first of the two substantially horizontal or inclined portions of the wellbore, wherein at least the first conductor comprises electrically conductive material; and

a power supply coupled to at least the first conductor, the power supply configured to electrically excite the electrically conductive materials of the first conductor such that current flows between the electrically conductive materials in the first conductor, through at least a portion of the formation, to a second conductor at least partially positioned in a second of the two substantially horizontal or inclined portions of the wellbore, and the current resistively heats at least a portion of the formation between the two substantially horizontally oriented or inclined portions of the wellbore.

411. The system of claim 410, wherein at least a portion of the first conductor and at least a portion of the second conductor are substantially parallel to each other.

412. The system of claim 410, wherein the second conductor is a ground conductor.

413. The system of claim 410, wherein the second conductor is at least partially positioned in a second of the two substantially horizontal or inclined portion of the wellbore.

414. The system of claim 410, wherein an average distance between the conductive portions of the first conductor and the second conductor is at least 10 meters.

415. The system of claim 410, wherein the first conductor comprises a conduit.

416. The system of claim 410, wherein the first conductor comprises a perforated conduit.

417. The system of claim 410, wherein the second conductor comprises a perforated conduit.

418. The system of claim 410, wherein at least one of the conductors comprises a first layer comprising carbon steel and a second layer comprising copper, and at least a portion of the second layer substantially surrounds or partially surrounds a portion of the first layer.

419. The system of claim 410, wherein at least one of the conductors comprises a portion positioned in an overburden section and the portion comprises one or more ferromagnetic materials.

420. The system of claim 410, wherein at least one of the conductors comprises a portion positioned in an overburden section and the portion comprises at least 15 percent by weight manganese.

421. The system of claim 410, wherein at least one of the conductors comprises a portion positioned in an overburden section and the portion comprises one or more ferromagnetic materials, and one or more of the ferromagnetic materials comprises at least 10 percent by weight manganese.

422. The system of claim 410, wherein at least one of the conductors comprises a portion positioned in an overburden section and the portion comprises one or more ferromagnetic materials, and one or more of the ferromagnetic materials comprises at least 10 percent by weight manganese, at least 5 percent by weight carbon, and at least 1 percent by weight chromium.

423. The system of claim 410, wherein at least one of the conductors is located in a wellbore comprising one or more electrical insulators.

424. The system of claim 410, wherein at least one of the conductors comprises a perforated conduit, the system further comprising a fluid injection system configured to inject fluid through at least some of the perforations and into the formation.

425. The system of claim 424, wherein the fluid comprises a drive fluid.

426. The system of claim 424, wherein the fluid comprises a foaming composition.

427. A method for treating a subsurface formation, comprising:

providing electrical current to a first conductor in a first substantially horizontal or inclined position in a section of the formation such that electrical current flows from the first conductor to a second conductor located in a second substantially horizontal or inclined position in the section of the formation, wherein the first conductor and the second conductor are located in wellbore sections that extend from a common wellbore; and

heating a least a portion of the hydrocarbon layer between the first and second conductors with heat generated by the electrical current flow.

428. The method of claim 427, wherein the first conductor extends from the vertical portion of the common wellbore, and wherein at least a portion of the first conductor extends horizontally

or inclined from the vertical portion and the first conductor comprises electrically conductive material.

429. The method of claim 427, wherein the second conductor extends from the vertical portion of the common wellbore, wherein at least a portion of the second conductor is substantially parallel to the first conductor; and wherein the second conductor comprises electrically conductive material.

430. The method of claim 427, further comprising creating increased fluid injectivity in at least portion of the section between the first conductor and the second conductor.

431. The method of claim 427, further comprising perforating at least a portion of the first conductor and/or the second conductor.

432. The method of claim 427, further comprising mobilizing at least some hydrocarbons in the formation with the generated heat.

433. The method of claim 432, further comprising producing at least a portion of the mobilized formation fluids from the formation.

434. The method of claim 427, further comprising injecting a foaming composition, and injecting a pressurizing fluid at a rate sufficient to foam the foaming composition in the section.

435. The method of claim 427, further comprising injecting a pre-foamed composition.

436. The method of claim 427, further comprising injecting a foaming composition, wherein the foaming composition comprises a surfactant.

437. The method of claim 427, wherein at least a portion of the first conductor is positioned in a shale layer of the formation.

438. The method of claim 427, wherein the second conductor is a ground conductor.

439. A method for treating a subsurface formation, comprising:

providing a hydrocarbon-containing feed stream produced from an in situ heat treatment process;

treating at least a portion of the hydrocarbon-containing feed stream with one or more aqueous acid compounds to produce an aqueous stream comprising organonitrogen compounds; and

providing at least a portion of the aqueous stream comprising the organonitrogen compounds to at least a portion of the formation that has been at least partially treated by the in situ-heat treatment process.

440. The method of claim 439, wherein at least a part of the formation in which the stream comprising organonitrogen compounds is injected comprises nahcolite.

441. The method of claim 439, wherein at least a part of the formation in which the stream comprising organonitrogen compounds is injected comprises nahcolite that has been treated using an in situ heat treatment process.

442. The method of claim 439, wherein at least a part of the formation in which the stream comprising organonitrogen compounds is injected comprises nahcolite, and wherein the stream comprising organonitrogen compounds is used as a source of fluid for solution mining.

443. The method of claim 439, wherein the treating of the hydrocarbon-containing stream with one or more aqueous acid compounds also produces a liquid stream, the liquid stream comprising non-organonitrogen hydrocarbons.

444. The method of claim 439, wherein the treating of the hydrocarbon-containing stream with one or more aqueous acid compounds also produces a non-aqueous stream, the non-aqueous stream comprising non-organonitrogen hydrocarbons; and further comprising hydrotreating at least a portion of the non-aqueous stream.

445. The method of claim 439, further comprising heating at least a portion of the aqueous stream comprising organonitrogen hydrocarbons to a temperature sufficient to at least form some non-organonitrogen containing hydrocarbons.

446. The method of claim 439, further comprising heating at least a portion of the aqueous stream comprising organonitrogen hydrocarbons to a temperature sufficient to at least form some non-organonitrogen containing hydrocarbons, and producing at least some of the non-organonitrogen containing hydrocarbons from the formation.

447. The method of claim 439, further comprising separating solids from at least a portion of the hydrocarbon-containing feed stream prior to treatment with at least one aqueous acid compound.

448. The method of claim 439, further comprising separating solids from at least a portion of the hydrocarbon-containing feed stream prior to treatment with at least one aqueous acid compound, and injecting the solids in the formation.

449. The method of claim 439, wherein the formation comprises oil shale.

450. A method for treating a nahcolite containing formation, comprising:

injecting a stream comprising organonitrogen compounds into the nahcolite containing formation that has been treated using an in situ heat treatment process to remove at least some of the nahcolite from the formation; and

producing formation fluids from the formation.

451. The method of claim 450, wherein the stream comprising organonitrogen compounds is produced using the in situ heat treatment process.

452. The method of claim 450, wherein removal of the nahcolite comprises solution mining the nahcolite and at least a portion of the stream comprising organonitrogen compounds is used as a fluid for the solution mining.

453. The method of claim 450, further comprising producing the stream from a hydrocarbon-containing stream by treating with one or more aqueous acid compounds.

454. The method of claim 453, wherein the producing of the stream with one or more aqueous acid compounds also produces a liquid stream, the liquid stream comprising non-organonitrogen hydrocarbons.

455. The method of claim 453, wherein the producing of the stream with one or more aqueous acid compounds also produces a non-aqueous stream, the non-aqueous stream comprising non-organonitrogen hydrocarbons, and further comprising hydrotreating at least a portion of the non-aqueous stream.

456. The method of claim 453, further comprising separating solids from at least a portion of the hydrocarbon-containing stream prior to treatment with at least one of the aqueous acid compounds.

457. The method of claim 453, further comprising separating solids from at least a portion of the hydrocarbon-containing stream prior to treatment with at least one of the aqueous acid compounds, and injecting the solids in the formation.

458. The method of claim 450, further comprising heating at least a portion of the stream comprising organonitrogen hydrocarbons to a temperature sufficient to form at least some non-nitrogen containing hydrocarbons.

459. The method of claim 450, further comprising heating at least a portion of the stream comprising organonitrogen hydrocarbons to a temperature sufficient to form at least some non-nitrogen containing hydrocarbons, and producing at least some of the non-nitrogen containing hydrocarbons from the formation.

460. A fitting for coupling ends of insulated conductors, comprising:

a sleeve configured to couple an end of a jacket of a first insulated conductor to an end of a jacket of a second insulated conductor, wherein the sleeve is located between end portions of the insulated conductors, at least one of the ends of the sleeve being angled relative to the longitudinal axis of the sleeve;

the sleeve having a longitudinal opening that extends along the length of the sleeve substantially the distance between end portions of the jackets of the insulated conductors, wherein the longitudinal opening is configured to allow electrically insulating material to be filled into the sleeve.

461. The fitting of claim 460, wherein both ends of the sleeve are angled relative to the longitudinal axis of the sleeve.

462. The fitting of claim 460, wherein the sleeve is substantially parallelogram shaped.

463. The fitting of claim 460, wherein the sleeve is configured to be centered between the end portions of the insulated conductors.

464. The fitting of claim 460, wherein the end portions of cores of the insulated conductors are configured to be coupled together inside the sleeve.

465. The fitting of claim 460, wherein the electrically insulating material comprises material substantially similar to electrical insulation in at least one of the two insulated conductors.

466. The fitting of claim 460, further comprising at least one ring inside the sleeve configured to reduce electrical fields in the sleeve.

467. The fitting of claim 460, wherein the coupling joint is configured to be operable at voltages above 1000 V and temperatures at or near 700 °C.

468. The fitting of claim 460, wherein at least one of the insulated conductors comprises electrical insulation that tapers at an angle from a jacket of the insulated conductor to a core of the insulated conductor inside the fitting.

469. A method for coupling ends of two insulated conductors, comprising:

placing a sleeve over end portions of one of the two insulated conductors to be coupled;

coupling end portions of cores of the two insulated conductors that extend between the two insulated conductors;

placing the sleeve over end portions of the two insulated conductors such that the sleeve covers the coupling between the end portions of the cores, wherein at least one of the ends of the sleeve is angled relative to the longitudinal axis of the sleeve;

coupling the sleeve to jackets of the end portions of the two insulated conductors;

filling the interior of the sleeve with electrically insulating material through a longitudinal opening in the sleeve that extends along the length of the sleeve substantially the distance between the end portions of the cores; and

covering the longitudinal opening such that the electrically insulating material is contained within the sleeve.

470. The method of claim 469, wherein both ends of the sleeve are angled relative to the longitudinal axis of the sleeve.

471. The method of claim 469, wherein the sleeve is substantially parallelogram shaped.

472. The method of claim 469, further comprising centering the sleeve between the end portions of the insulated conductors.

473. The method of claim 469, further comprising coupling the end portions of the cores of the two insulated conductors by welding together the portions.

474. The method of claim 469, further comprising coupling the sleeve to the end portions of the jackets of the two insulated conductors by welding the sleeve to the end portions.

475. The method of claim 469, wherein the electrically insulating material comprises material substantially similar to electrical insulation in at least one of the insulated conductors.

476. The method of claim 469, further comprising vibrating at least the sleeve during filling of the electrically insulating material into the sleeve, and applying a compressive pressure to the electrically insulating material prior to covering the longitudinal opening.

477. The method of claim 469, further comprising installing the insulated conductors in a subsurface formation.

478. The method of claim 469, further comprising applying electrical current to the insulated conductors, and providing heat from at least one of the insulated conductors to at least a portion of a subsurface formation.

479. The method of claim 469, wherein the coupling joint is configured to be operable at voltages above 1000 V and temperatures at or near 700 °C.

480. A fitting for coupling an end of a first insulated conductor to an end of a second insulated conductor, comprising:

a first splice housing configured to be placed over the end of the first insulated conductor and coupled to the first insulated conductor, the first splice housing having an interior volume that tapers from a larger diameter at the end of the first splice housing facing the end of the first insulated conductor to a smaller diameter at or near the end of the first splice housing configured to be coupled to the first insulated conductor;

a second splice housing configured to be placed over the end of the second insulated conductor and coupled to the second insulated conductor, the second splice housing having an interior volume that tapers from a larger diameter at the end of the second splice housing facing the end of the second insulated conductor to a smaller diameter at or near the end of the second splice housing configured to be coupled to the second insulated conductor; and

a sleeve configured to be located over the end of the second insulated conductor and adjacent to the second splice housing, the sleeve being configured to be coupled to at least one of the splice housings;

wherein an interior volume of the fitting is configured to be substantially filled with electrically insulating material, and the interior volume of the fitting is configured to be reduced such that the electrically insulating material substantially filling the interior volume is compacted.

481. The fitting of claim 480, wherein the electrically insulating material, when compacted, comprises substantially similar dielectric characteristics to electrical insulation in at least one of the two insulated conductors.

482. The fitting of claim 480, wherein cores of the insulated conductors are configured to be coupled together in the interior volume of the fitting.

483. The fitting of claim 480, wherein the interior volume of the fitting is configured to be reduced by forcing the first splice housing and the second splice housing together.

484. The fitting of claim 480, wherein the electrically insulating material is configured to be compacted by a pressure of at least 25,000 pounds per square inch.

485. The fitting of claim 480, wherein the electrically insulating material is configured to be compacted by application of vibration along with reduction of the interior volume of the fitting.

486. The fitting of claim 480, wherein the fitting is configured to be centered between the ends of the insulated conductors.

487. The fitting of claim 480, wherein the diameter of the interior volume of the first splice housing at or near the end configured to be coupled to the first insulated conductor is less than the outside diameter of the first insulated conductor.

488. The fitting of claim 480, wherein the diameter of the interior volume of the first splice housing at or near the end configured to be coupled to the first insulated conductor is substantially the same as the outside diameter of the first insulated conductor.

489. The fitting of claim 480, wherein the interior volume of the fitting is configured to be reduced by applying hydraulic pressure.

490. The fitting of claim 480, wherein the interior volume of the fitting is configured to be reduced using a swaging method.

491. The fitting of claim 480, wherein the electrically insulating material comprises material substantially similar to electrical insulation in at least one of the two insulated conductors.

492. The fitting of claim 480, wherein the sleeve and the splice housings have geometries that reduce electrical field intensity at the interface of the fitting and the insulated conductor when the fitting is coupled to the insulated conductor.

493. The fitting of claim 480, wherein at least one of the insulated conductors is configured to be used to heat a subsurface formation.

494. The fitting of claim 480, wherein at least one of the insulated conductors comprises electrical insulation that tapers at an angle from a jacket of the insulated conductor to a core of the insulated conductor inside the fitting.

495. The fitting of claim 480, wherein the first splice housing is configured to be slid over the end of the first insulated conductor.

496. The fitting of claim 480, wherein the second splice housing is configured to be slid over the end of the second insulated conductor.

497. A method for coupling an end of a first insulated conductor to an end of a second insulated conductor, comprising:

placing a first splice housing over the end of the first insulated conductor;

placing a second splice housing over the end of the second insulated conductor;

placing a sleeve over the second insulated conductor and the second splice housing such that the sleeve is substantially adjacent to the second splice housing and located over the end of the second insulated conductor;

coupling the first splice housing to the first insulated conductor;

bringing the second splice housing and the sleeve together with the first splice housing such that the splice housings and the sleeve form a fitting with an interior volume;

substantially filling at least a majority of the interior volume of the fitting with electrically insulating material;

reducing the interior volume of the fitting such that the electrically insulating material substantially filling the interior volume is compacted;

coupling the sleeve to the second splice housing; and

coupling the second splice housing to the second insulated conductor.

498. The method of claim 497, wherein the first and second splice housings have interior volumes that taper from larger diameters at or near the ends of the splice housings facing each other to smaller diameters at or near the ends of the splice housings coupled to the insulated conductors.

499. The method of claim 497, further comprising coupling a core of the first insulated conductor to a core of the second insulated conductor.

500. The method of claim 497, further comprising reducing the interior volume of the fitting by forcing the first splice housing and the second splice housing together.

501. The method of claim 497, further comprising reducing the interior volume of the fitting after the second splice housing is coupled to the second insulated conductor.

502. The method of claim 497, wherein the compacted electrically insulating material comprises substantially similar dielectric characteristics to electrical insulation in at least one of the two insulated conductors.

503. The method of claim 497, further comprising installing the insulated conductors and the fitting in a subsurface formation.

504. The method of claim 497, further comprising applying electrical current to the insulated conductors, and providing heat from at least one of the insulated conductors to at least a portion of a subsurface formation.

505. The method of claim 497, further comprising compacting the electrically insulating material with a pressure of at least 25,000 pounds per square inch.

506. The method of claim 497, further comprising sliding the first splice housing over the end of the first insulated conductor, sliding the second splice housing over the end of the second insulated conductor, and sliding the sleeve over the second insulated conductor and the second splice housing.

507. A method for assessing a temperature in an opening in a subsurface formation, comprising:

assessing one or more dielectric properties along a length of an insulated conductor located in the opening; and

assessing one or more temperatures along the length of the insulated conductor based on the one or more assessed dielectric properties.

508. The method of claim 507, further comprising providing electrical power to at least a portion of the insulated conductor, and providing at least some heat to the subsurface formation from the portion of the insulated conductor.

509. The method of claim 507, further comprising providing electrical power to at least one additional insulated conductor located in the opening, and providing at least some heat to the subsurface formation from the additional insulated conductor.

510. The method of claim 507, wherein assessing the one or more temperatures comprises comparing temperature dependence data of the dielectric properties to the assessed dielectric properties.

511. The method of claim 507, wherein at least one of the dielectric properties comprises a dielectric constant.

512. The method of claim 507, wherein at least one of the dielectric properties comprises a loss tangent.

513. The method of claim 507, wherein the one or more assessed temperatures are above about 400 °C.

514. The method of claim 507, wherein the one or more assessed temperatures are in a range between about 400 °C and about 900 °C.

515. The method of claim 507, wherein the one or more assessed temperatures are distributed at different locations along the length of the insulated conductor.

516. The method of claim 507, further comprising assessing the one or more temperatures using a computational system configured to store temperature dependence data of the dielectric properties.

517. The method of claim 507, wherein the length of the insulated conductor assessed comprises at most an upper half of the insulated conductor.

518. The method of claim 507, wherein the insulated conductor comprises a core, an insulation material surrounding the core, and an outer sheath surrounding the insulation material.

519. The method of claim 507, wherein the insulated conductor comprises insulation material that has properties that vary along the length of the insulated conductor.

520. A method for assessing a temperature at one or more locations in an opening in a subsurface formation, comprising:

applying a voltage to an insulated conductor locating in the opening, wherein at least a portion of the insulated conductor comprises a core substantially surrounded by an electrical insulator and a jacket, respectively, and the electrical insulator comprises a salt configured to melt at a desired temperature; and

assessing at least one location along the length of the insulated conductor where the salt has melted by assessing the current flowing through the core and the jacket of the insulated conductor.

521. The method of claim 520, further comprising providing heat from one or more heaters located in the opening, wherein at least one of the locations assessed along the length of the insulated conductor comprises a hotspot generated by at least one of the heaters.

522. The method of claim 520, wherein the locations at which the salt has melted are hotter than other portions of the opening.

523. The method of claim 520, further comprising providing at least one incident pulse to the insulated conductor, and assessing one or more reflected pulses to assess one or more locations along the length of the insulated conductor at which the salt has melted.

524. The method of claim 520, wherein the desired temperature is above about 300 °C.

525. The method of claim 520, wherein the desired temperature is in a range between about 300 °C and about 900 °C.

526. The method of claim 520, wherein at least two of the locations at which the salt has melted are distributed at different locations along the length of the insulated conductor.

527. The method of claim 520, wherein the salt comprises a mixture of salts.

528. The method of claim 520, wherein the electrical insulator comprises porous magnesium oxide with salt located in the pores of the magnesium oxide.

529. A method for assessing a temperature at one or more locations in an opening in a subsurface formation, comprising:

providing a voltage with at least one incident pulse to an insulated conductor locating in the opening, wherein at least a portion of the insulated conductor comprises a core substantially surrounded by an electrical insulator and a jacket, respectively, and the electrical insulator comprises a salt configured to melt in a desired temperature range; and

assessing at least one location along the length of the insulated conductor at which the salt has melted by assessing at least one property of at least one pulse reflected from at least one of the locations at which the salt has melted.

530. The method of claim 529, further comprising providing heat from one or more heaters located in the opening, wherein at least one of the locations assessed along the length of the insulated conductor comprises a hotspot generated by at least one of the heaters.

531. The method of claim 529, wherein the locations at which the salt has melted are hotter than other portions of the opening.

532. The method of claim 529, further comprising assessing at least one of the locations at which the salt has melted using time domain reflectometry.

533. The method of claim 529, further comprising assessing at least one of the locations at which the salt has melted by assessing a transit time between the incident and reflected pulses.

534. The method of claim 529, wherein the desired temperature is above about 300 °C.

535. The method of claim 529, wherein the desired temperature is in a range between about 300 °C and about 900 °C.

536. The method of claim 529, wherein at least two of the locations at which the salt has melted are distributed at different locations along the length of the insulated conductor.

537. The method of claim 529, wherein the salt comprises a mixture of salts.

538. The method of claim 529, wherein the electrical insulator comprises porous magnesium oxide with salt located in the pores of the magnesium oxide.

539. A method for treating a tar sands formation, comprising:

providing heat from a first heater located between a steam injection well and a production well in a hydrocarbon containing layer of the formation, wherein the first heater, the steam injection well, and the production well are located substantially horizontally in the hydrocarbon containing layer;

providing heat from a second heater horizontally offset from the first heater, the second heater being located vertically above an injection/production well in the hydrocarbon containing layer, the second heater being located substantially horizontally in the hydrocarbon containing layer;

injecting steam into the hydrocarbon containing layer through the steam injection well after a selected amount of heat is provided from the first heater;

producing hydrocarbons from the layer through the production well; and

alternately injecting steam and producing hydrocarbons through the injection/production well after a selected amount of heat is provided from the second heater.

540. The method of claim 539, wherein the first heater is approximately vertically equidistant between the steam injection well and the production well.

541. The method of claim 539, wherein the steam is injected through the steam injection well at a pressure that is above the formation fracturing pressure and below the overburden fracture pressure of the formation.

542. The method of claim 539, wherein the steam is injected through the injection/production well at a pressure that is above the formation fracturing pressure and below the overburden fracture pressure of the formation.

543. The method of claim 539, wherein steam injected through the steam injection well is at least 0.5 MPa below the pressure of steam injected through the injection/production well.

544. The method of claim 539, wherein the first heater and/or the second heater are electric heaters.

545. The method of claim 539, wherein the first heater and/or the second heater provide heat at a heat injection rate of at least about 1000 watts per meter.

546. The method of claim 539, wherein the selected amount of heat provided from the first heater creates sufficient steam injectivity between the steam injection well and the production well for injection of the steam from the steam injection well to move hydrocarbons to the production well.

547. The method of claim 539, wherein the selected amount of heat provided from the first heater is reached after about one year of heating using the first heater.

548. The method of claim 539, wherein the selected amount of heat provided from the second heater creates sufficient steam injectivity around the injection/production well for injection of the steam from the injection/production well.

549. The method of claim 539, wherein the selected amount of heat provided from the second heater is reached after about one year of heating using the second heater.

550. The method of claim 539, wherein the injection/production well is located substantially horizontally in the hydrocarbon containing layer.

551. The method of claim 539, wherein the first heater is turned off on or about the time injection of steam through the steam injection well is started.

552. The method of claim 539, wherein the second heater is turned off on or about the time steam injection interconnectivity between the injection/production well and the production well is achieved.

553. The method of claim 539, wherein the initial vertical matrix permeability in the hydrocarbon containing layer is at most about 300 millidarcy.

554. The method of claim 539, wherein the initial horizontal matrix permeability in the hydrocarbon containing layer is at most about 1 darcy.

555. The method of claim 539, wherein the initial viscosity of fluid in the hydrocarbon containing layer is at least about 1 x 10^6 centipoise.

556. The method of claim 539, wherein the hydrocarbon containing layer has an initial permeability that is heterogenous.

557. The method of claim 539, wherein providing heat to the hydrocarbon containing layer from the first heater and/or the second heater increases the steam injectivity in the layer.

558. A method for treating a tar sands formation, comprising:

providing heat from a first heater located between a steam injection well and a production well in a hydrocarbon containing layer of the formation, wherein the first heater, the steam injection well, and the production well are located substantially horizontally in the hydrocarbon containing layer;

injecting steam into the hydrocarbon containing layer through the steam injection well after a selected amount of heat is provided from the first heater; and

producing hydrocarbons from the layer through the production well.

559. The method of claim 558, wherein the first heater is approximately vertically equidistant between the steam injection well and the production well.

560. The method of claim 558, wherein the steam is injected through the steam injection well at a pressure that is above the formation fracturing pressure and below the overburden fracture pressure of the formation.

561. The method of claim 558, wherein the first heater is an electric heater.

562. The method of claim 558, wherein the first heater provides heat at a heat injection rate of at least about 1000 watts per meter.

563. The method of claim 558, wherein the selected amount of heat provided from the first heater creates sufficient steam injectivity between the steam injection well and the production well for injection of the steam from the steam injection well to move hydrocarbons to the production well.

564. The method of claim 558, wherein the selected amount of heat provided from the first heater is reached after about one year of heating using the first heater.

565. The method of claim 558, wherein the first heater is turned off on or about the time injection of steam through the steam injection well is started.

566. The method of claim 558, wherein the initial vertical matrix permeability in the hydrocarbon containing layer is at most about 300 millidarcy.

567. The method of claim 558, wherein the initial horizontal matrix permeability in the hydrocarbon containing layer is at most about 1 darcy.

568. The method of claim 558, wherein the initial viscosity of fluid in the hydrocarbon containing layer is at least about 1 x 10^6 centipoise.

569. The method of claim 558, wherein the hydrocarbon containing layer has an initial permeability that is heterogenous.

570. The method of claim 558, wherein providing heat to the hydrocarbon containing layer from the first heater increases the steam injectivity in the layer.

571. A method of recovering energy from a subsurface hydrocarbon containing formation, comprising:

introducing an oxidizing fluid in a wellbore positioned in at least a first portion of a subsurface hydrocarbon containing formation, wherein at least a portion of the first portion of the subsurface hydrocarbon containing formation has been subjected to an in situ heat treatment process prior to introduction of the oxidizing fluid, and wherein the portion comprises a treatment area comprising elevated levels of coke substantially adjacent the wellbore;

increasing the pressure in the wellbore by introducing the oxidizing fluid under pressure such that the oxidizing fluid substantially permeates a majority of the treatment area and initiates a combustion process;

allowing heat from the combustion process to transfer to fluids in the treatment area;

decreasing the pressure in the wellbore such that heated fluids from the portion of the formation are conveyed into the wellbore; and

transferring heated fluids conveyed into the wellbore to the surface to a heat exchanger configured to collect thermal energy.

572. The method of claim 571, wherein the treatment area comprises residual hydrocarbons.

573. The method of claim 571, wherein the heated fluids comprise at least some heated oxidizing fluid.

574. The method of claim 571, wherein the heated fluids comprise at least some products from the combustion process.

575. The method of claim 571, further comprising transferring a heated heat transfer fluid from the heat exchanger to at least a second portion of the subsurface hydrocarbon containing formation.

576. The method of claim 575, wherein the heat transfer fluid comprises molten salt.

577. The method of claim 575, wherein the heat transfer fluid comprises molten metal.

578. The method of claim 575, wherein the heat transfer fluid comprises condensable hydrocarbons.

579. The method of claim 575, wherein the heat transfer fluid comprises thermally conductive gases.

580. The method of claim 579, wherein the thermally conductive gases comprise helium, carbon dioxide, and/or steam.

581. The method of claim 571, further comprising transferring a heated heat transfer fluid from the heat exchanger to at least a second portion of the subsurface hydrocarbon containing formation such that at least the second portion is heated using the heated heat transfer fluid.

582. The method of claim 571, further comprising creating a barrier, wherein the barrier is configured to inhibit oxidizing fluid introduced in the wellbore from being conveyed beyond the treatment area substantially adjacent the wellbore.

583. The method of claim 571, further comprising introducing a barrier forming fluid around the treatment area substantially adjacent the wellbore, wherein the barrier fluid is configured to solidify at or below a specified temperature range.

584. The method of claim 583, wherein the barrier forming fluid comprises a slurry.

585. The method of claim 583, wherein the barrier forming fluid comprises a slurry comprising solids and a low volatility solvent.

586. The method of claim 583, wherein the barrier forming fluid comprises ceramics, micas, and/or clays.

587. The method of claim 571, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore.

588. The method of claim 571, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a flow rate of the oxidizing fluid.

589. The method of claim 571, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting the change in pressure.

590. The method of claim 571, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a duration of the combustion process.

591. The method of claim 571, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by injecting steam in the wellbore.

592. The method of claim 571, further comprising conducting a cycling process, wherein the cycling process comprises repeatedly:

increasing the pressure in the wellbore using the oxidizing fluid; and

decreasing the pressure in the wellbore to remove at least some of the combustion products.

593. The method of claim 592, further comprising introducing sufficient oxidizing fluid in the wellbore such that the combustion process proceeds throughout the cycling process of the wellbore.

594. The method of claim 571, further comprising inhibiting heat loss in an overburden in at least the first portion of the subsurface hydrocarbon containing formation by insulating at least the portion of the wellbore in the overburden.

595. A method of recovering energy from a subsurface hydrocarbon containing formation, comprising:

introducing an oxidizing fluid in a wellbore positioned in at least a first portion of a subsurface hydrocarbon containing formation, wherein at least a portion of the first portion of the subsurface hydrocarbon containing formation has been subjected to an in situ heat treatment process prior to introduction of the oxidizing fluid, and wherein the portion comprises a treatment area comprising elevated levels of coke substantially adjacent the wellbore;

increasing the pressure in the wellbore by introducing the oxidizing fluid under pressure such that the oxidizing fluid substantially permeates a majority of the treatment area and initiates a combustion process;

allowing heat from the combustion process to transfer to fluids in the treatment area;

decreasing the pressure in the wellbore such that at least some heated fluids from the treatment area are conveyed into the wellbore; and

introducing a heat transfer fluid in the wellbore such that heat is transferred from the wellbore to the heat transfer fluid.

596. The method of claim 595, wherein the treatment area comprises residual hydrocarbons.

597. The method of claim 595, wherein the heated fluids comprise at least some heated oxidizing fluid.

598. The method of claim 595, wherein the heated fluids comprise at least some products from the combustion process.

599. The method of claim 595, further comprising transferring the heated heat transfer fluid from the wellbore to at least a second portion of the subsurface hydrocarbon containing formation.

600. The method of claim 595, further comprising transferring the heated heat transfer fluid from the wellbore to at least a second portion of the subsurface hydrocarbon containing formation such that at least the second portion is heated using the heated heat transfer fluid.

601. The method of claim 595, further comprising creating a barrier, wherein the barrier is configured to inhibit oxidizing fluid introduced in the wellbore from being conveyed beyond the treatment area substantially adjacent the wellbore.

602. The method of claim 595, further comprising introducing a barrier forming fluid around the treatment area substantially adjacent the wellbore, wherein the barrier fluid is configured to solidify at or below a specified temperature range.

603. The method of claim 602, wherein the barrier forming fluid comprises a slurry.

604. The method of claim 602, wherein the barrier forming fluid comprises a slurry comprising solids and a low volatility solvent.

605. The method of claim 602, wherein the barrier forming fluid comprises ceramics, micas, and/or clays.

606. The method of claim 595, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore.

607. The method of claim 595, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a flow rate of the oxidizing fluid.

608. The method of claim 595, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting the change in pressure.

609. The method of claim 595, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by adjusting a duration of the combustion process.

610. The method of claim 595, further comprising regulating the temperature of the wellbore and/or the treatment area substantially adjacent the wellbore by injecting steam in the wellbore.

611. The method of claim 595, further comprising conducting a cycling process, wherein the cycling process comprises repeatedly:

increasing the pressure in the wellbore using the oxidizing fluid; and

decreasing the pressure in the wellbore to remove at least some of the combustion products.

612. The method of claim 611, further comprising introducing sufficient oxidizing fluid in the wellbore such that the combustion process proceeds throughout the cycling process of the wellbore.

613. The method of claim 595, further comprising inhibiting heat loss in an overburden in at least the first portion of the subsurface hydrocarbon containing formation by insulating at least the portion of the well bore in the overburden.

614. The method of claim 595, wherein the heat transfer fluid comprises molten salt.

615. The method of claim 595, wherein the heat transfer fluid comprises molten metal.

616. The method of claim 595, wherein the heat transfer fluid comprises condensable hydrocarbons.

617. The method of claim 595, wherein the heat transfer fluid comprises thermally conductive gases.

618. The method of claim 617, wherein the thermally conductive gases comprise helium, carbon dioxide, and/or steam.

619. A method of heating a subsurface hydrocarbon containing formation, comprising:

providing heat flux per volume to a first portion of a subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more first heat sources positioned in the first portion; and

providing heat flux per volume to a second portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more second heat sources positioned in the second portion, wherein the heat flux per volume provided by the two or more second heat sources is greater than the heat flux per volume provided by the two or more first heat sources, and wherein the second portion is positioned below the first portion.

620. The method of claim 619, further comprising pyrolyzing at least some of the hydrocarbons in the second portion.

621. The method of claim 619, further comprising:

pyrolyzing at least some of the hydrocarbons in the second portion; and

heating at least some of the first portion with at least some of the pyrolysis products from the second portion.

622. The method of claim 619, further comprising increasing the pressure in the formation to between about 2070 kPa and about 3450 kPa psi.

623. The method of claim 619, further comprising:

increasing the pressure in the formation to between about 2070 kPa and about 3450 kPa for a period of time; and

decreasing the pressure in the formation to between about 500 kPa and about 1000 kPa after the period of time.

624. The method of claim 619, further comprising:

increasing the pressure in the formation to between about 2070 kPa and about 3450 kPa for a period of 200 days to 600 days, 300 days to 500 days, or 350 days to 450 days; and

decreasing the pressure in the formation to between about 500 kPa and about 1000 kPa after the period of time.

625. The method of claim 619, wherein the heat flux per volume provided to the first portion is limited such that pyrolysis of hydrocarbons is inhibited in the first portion of the formation.

626. The method of claim 619, wherein the second portion of the formation comprises about a third of the formation positioned below an overburden.

627. The method of claim 619, wherein the first portion of the formation comprises about two thirds of the formation positioned below an overburden.

628. The method of claim 619, wherein the first portion of the formation comprises about two thirds of the formation positioned below an overburden, and wherein about 20 percent less heat flux per volume is provided to the first portion relative to the second portion.

629. The method of claim 619, wherein the first portion of the formation comprises about two thirds of the formation positioned below an overburden, and wherein about 20 percent less heat flux per volume is provided to the first portion relative to the second portion within the first five years of initially providing heat flux at least a portion of the formation.

630. The method of claim 619, further comprising providing heat flux per volume to a third portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more third heat sources positioned in the third portion, and wherein the third portion is positioned below the first portion and above the second portion.

631. The method of claim 619, further comprising providing heat flux per volume to a third portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more third heat sources positioned in the third portion, wherein the heat flux per volume provided by the two or more second heat sources is greater than the heat flux per volume provided by the two or more third heat sources, and wherein the third portion is positioned below the first portion and above the second portion.

632. The method of claim 619, further comprising providing heat flux per volume to a third portion of the subsurface hydrocarbon containing formation, wherein the heat flux per volume is provided by two or more third heat sources positioned in the third portion, wherein the heat flux per volume provided by the two or more second heat sources is greater than the heat flux per volume provided by the two or more third heat sources, wherein the heat flux per volume provided by the two or more third heat sources is greater than the heat flux per volume provided by the two or more first heat sources, and wherein the third portion is positioned below the first portion and above the second portion.

633. The method of claim 619, further comprising positioning a production well in or adjacent to the second portion of the formation.

634. The method of claim 619, further comprising positioning a production well in or adjacent to the second portion of the formation, wherein spacing for heat sources adjacent to the production well are horizontally and/or vertically irregularly offset from the production well.

635. The method of claim 619, further comprising positioning a production well in or adjacent to the second portion of the formation such that hydrocarbons are removed from the second portion of the formation.

636. The method of claim 619, further comprising:

positioning a production well in or adjacent to the second portion of the formation; and

removing hydrocarbons from the second portion of the formation such that hydrocarbons from the first portion are conveyed towards the first portion of the formation.

637. The method of claim 619, further comprising:

positioning a producer well in or adjacent to the second portion of the formation;

removing hydrocarbons from the second portion of the formation such that hydrocarbons from the first portion are conveyed towards the first portion of the formation; and

pyrolyzing in the second portion at least some of the hydrocarbons conveyed from the first portion.

638. The method of claim 619, wherein the second portion of the formation comprises more second heat sources than the first portion comprises first heat sources.

639. The method of claim 619, wherein two or more of the second heat sources initiate heating before two or more of the first heat sources.

640. A system for heating a subsurface formation, comprising:

a heater wellbore located in a subsurface formation;

a single conducting heater element comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and

a heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising an electrically non-conducting portion and an electrically conducting portion;

wherein the non-conducting portion begins at the surface of the formation, the conducting portion is located between the non-conducting portion and the heated portion of the heater, and the non-conducting portion extends to a depth that is at least about 30 m above the heated portion of the heater.

641. The system of claim 640, wherein the non-conducting portion is configured to inhibit induction of surface potentials from the lead-in portion of the heater in the overburden of the formation.

642. The system of claim 640, wherein the non-conducting portion is configured to inhibit linear current induction in conductors at the surface of the formation.

643. The system of claim 640, wherein the non-conducting portion is configured to inhibit voltage potential induction in conductors at the surface of the formation.

644. The system of claim 640, wherein the lead-in portion of the heater comprises a single conducting element.

645. The system of claim 640, wherein the non-conducting portion comprises fiberglass.

646. The system of claim 640, wherein the depth of at least about 30 m is greater than at least twice the distance between the heater wellbore and a closest additional heater wellbore in the formation, wherein the closest additional heater wellbore comprises an additional single conducting element having a polarity opposite the single conducting element.

647. The system of claim 640, wherein the non-conducting portion extends to a depth that is at least about 100 m above the heated portion of the heater.

648. The system of claim 640, wherein the non-conducting portion extends to a depth that is at least about 150 m above the heated portion of the heater.

649. A system for heating a subsurface formation, comprising:

a heater wellbore located in a subsurface formation;

a heater comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden, and the heated part comprises a single conducting element; and

a heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising an electrically non-conducting portion and an electrically conducting portion;

wherein the non-conducting portion begins at the surface of the formation, the conducting portion is located between the non-conducting portion and the heated portion of the heater, and the non-conducting portion extends to a depth of at least about 10 m below the surface.

650. The system of claim 649, wherein the non-conducting portion is configured to inhibit induction of surface potentials from the lead-in portion of the heater in the overburden of the formation.

651. The system of claim 649, wherein the non-conducting portion is configured to inhibit linear current induction in conductors at the surface of the formation.

652. The system of claim 649, wherein the non-conducting portion is configured to inhibit voltage potential induction in conductors at the surface of the formation.

653. The system of claim 649, wherein the lead-in portion of the heater comprises a single conducting element.

654. The system of claim 649, wherein the non-conducting portion comprises fiberglass.

655. The system of claim 649, wherein the depth of at least about 10 m is greater than a distance between the heater wellbore and a closest additional heater wellbore in the formation.

656. A system for heating a subsurface formation, comprising:

a heater wellbore located in a subsurface formation;

a single conducting heater element comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and

a heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising an electrically non-conducting portion and an electrically conducting portion;

wherein the non-conducting portion begins at the surface of the formation, the conducting portion is located between the nonconducting portion and the heated portion of the heater, and the nonconducting portion extends to at least to a depth that is at least below a surface moisture zone of the formation.

657. The system of claim 656, wherein the non-conducting portion is configured to inhibit induction of surface currents and potentials from the lead-in portion of the heater in the overburden of the formation.

658. The system of claim 656, wherein the lead-in portion of the heater comprises a single conducting element.

659. The system of claim 656, wherein the non-conducting portion comprises fiberglass.

660. The system of claim 656, wherein the non-conducting portion extends to a depth that is greater than a distance between the heater wellbore and a closest additional heater wellbore in the formation.

661. The method of claim 656, wherein the single conducting heater element of the wellbore has a polarity opposite of a single conducting heater element of an adjacent wellbore having a heater casing located in the overburden portion of the adjacent wellbore, the heater casing comprising a non-conduction portion, wherein the non-conducting portions of the heater-casings of the heater wellbore and the adjacent heater wellbore extend to depths that are twice the distance between the heater wellbore and the adjacent additional wellbore in the formation.

662. A system for heating a subsurface formation, comprising:

a first heater wellbore in a plurality of heater wellbores located in a subsurface formation, the first heater wellbore comprising:

a first single conducting heater element comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden; and

a first heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising a first electrically non-conducting portion and a first electrically conducting portion, wherein the first conducting portion is located between the first non-conducting portion and the heated portion of the heater; and

a second heater wellbore of a plurality of heater wellbores, the second heater wellbore adjacent to the first heater wellbore, the second heater wellbore comprising:

a second single conducting heater element comprising a heated portion located in a part of the subsurface formation configured to be heated and a lead-in portion located in an overburden of the subsurface formation, wherein the heated part is located below the overburden and the second single conducting heater element has a polarity opposite of the first single conducting heater element; and

a second heater casing located substantially in an overburden portion of the heater wellbore, the heater casing comprising a second electrically non-conducting portion and a second electrically conducting portion, wherein the second conducting portion is located between the second non-conducting portion and the heated portion of the heater;

wherein the first and second non-conducting portions extend to depths at least twice a distance between the first wellbore and the second wellbore.

663. A heating system for a subsurface formation, comprising:

a first tubular located in the subsurface formation;

a second tubular, wherein at least a portion of the first tubular is positioned in the second tubular; and

two or more elongated electrical conductors, wherein at least a portion of the electrical conductors are positioned between an outer surface of the first tubular and an inner surface of the second tubular;

wherein the electrical conductors are configured to provide heat to the subsurface formation when an electrical current is applied to the electrical conductors.

664. The heating system of claim 663, wherein the elongated electrical conductors are configured to contact the inner surface of the second tubular.

665. The heating system of claim 663, wherein the elongated electrical conductors are located in a substantially horizontal section of a wellbore.

666. The heating system of claim 665, wherein the wellbore comprises a relatively vertical section connecting the substantially horizontal section to the surface of the formation.

667. The heating system of claim 663, wherein the electrical conductors comprise a lead-in section that provides little or no heat at or near a junction between a substantially horizontal section of a wellbore and a relatively vertical section of the wellbore.

668. The heating system of claim 663, wherein the electrical conductors are configured to provide heat to a hydrocarbon containing layer in the subsurface formation when the electrical current is applied to the electrical conductors.

669. A system for producing fluids from a subsurface formation, comprising:

a wellbore in the subsurface formation, wherein the wellbore is configured to allow fluids from the formation to enter a substantially horizontal section of the wellbore;

a first tubular located in the wellbore, wherein the first tubular has an opening at an end of the first tubular distal from the surface of the formation;

a second tubular in the wellbore, wherein at least a portion of the first tubular is positioned in the second tubular; and

two or more elongated electrical conductors, wherein at least a portion of the electrical conductors are positioned between an outer surface of the first tubular and an inner surface of the second tubular;

wherein the electrical conductors are configured to provide heat in the wellbore when an electrical current is applied to the electrical conductors; and

wherein the system is configured to produce fluids that enter the wellbore to the surface of the formation through the inside of the first tubular.

670. The system of claim 669, wherein the substantially horizontal section of the wellbore is located in a hydrocarbon containing layer of the formation.

671. The system of claim 669, wherein the electrical conductors are located in the substantially horizontal section of the wellbore.

672. The system of claim 669, wherein the wellbore comprises a relatively vertical section connecting the substantially horizontal section to the surface of the formation, and the system is configured to gas lift fluids through the relatively vertical section.

673. The system of claim 669, wherein the electrical conductors comprise a lead-in section that provides little or no heat at or near a junction between the substantially horizontal section of the wellbore and a relatively vertical section of the wellbore.

674. The system of claim 669, wherein the elongated electrical conductors are configured to contact the inner surface of the second tubular.

675. A method for producing fluids from a subsurface formation, comprising:

allowing fluids to enter a substantially horizontal section of a wellbore in the subsurface formation;

producing at least some of the fluids through the inside of a first tubular located in the wellbore, wherein the produced fluids enter the first tubular through an opening located at an end of the first tubular distal from the surface of the formation; and

providing heat to at least a part of the substantially horizontal section of the wellbore by applying electrical current to two or more electrical conductors positioned between the outer surface of the first tubular and the inner surface of a second tubular that at least partially surrounds the first tubular.

676. The method of claim 675, wherein the substantially horizontal section of the wellbore is located in a hydrocarbon containing layer of the formation.

677. The method of claim 675, wherein the electrical conductors are located in the substantially horizontal section of the wellbore.

678. The method of claim 675, further comprising gas lifting the produced fluids through a relatively vertical section of the wellbore to the surface of the formation, wherein the relatively vertical section connects the substantially horizontal section of the wellbore to the surface of the formation.

679. The method of claim 675, further comprising providing little or no heat at or near a junction between the substantially horizontal section of the wellbore and a relatively vertical section of the wellbore.

680. The method of claim 675, further comprising forcing fluids to enter the first tubular at the distal end of the first tubular.

681. A fitting for coupling an end of a first insulated conductor to an end of a second insulated conductor, comprising:

a sleeve configured to be placed over the end of the first insulated conductor and the end of the second insulated conductor; and

a core coupling located inside the sleeve, the core coupling being configured to fit around an end of a core of the first insulated conductor and an end of a core of the second insulated conductor;

wherein an interior volume of the sleeve is configured to be at least partially filled with electrically insulating material, and the electrically insulating material is configured to be compressed with an end portion of an electrical insulator in the first insulated conductor and an

end portion of an electrical insulator in the second insulated conductor when the fitting is coupled to the insulated conductors.

682. The fitting of claim 681, wherein the insulated conductors are configured to be pressed into the fitting and compact the electrically insulating material into the electrical insulators of the insulated conductors.

683. The fitting of claim 681, wherein cores of the insulated conductors are configured to be pressed together in the core coupling when the ends of the insulated conductors are moved into the fitting.

684. The fitting of claim 681, wherein the sleeve comprises one or more grooves to inhibit electrically insulating material from moving out of the sleeve.

685. The fitting of claim 681, wherein at least one of the insulated conductors comprises electrical insulation that tapers at an angle from a jacket of the insulated conductor to a core of the insulated conductor inside the fitting.

686. The fitting of claim 681, wherein the core coupling comprises a tapered inside diameter with a smaller diameter at the center of the coupling to enhance contact with the cores of the insulated conductors.

687. The fitting of claim 681, wherein the core coupling comprises one or more grooves on the inside diameter of the coupling to enhance contact with the cores of the insulated conductors.

688. The fitting of claim 681, wherein the electrically insulating material is configured to be compacted by a pressure of at least 25,000 pounds per square inch.

689. The fitting of claim 681, wherein the electrically insulating material is configured to be compacted by application of vibration along with reduction of an interior volume of the fitting.

690. The fitting of claim 681, wherein the fitting is configured to be centered between the ends of the insulated conductors.

691. The fitting of claim 681, wherein an interior volume of the fitting is configured to be reduced by applying hydraulic pressure.

692. The fitting of claim 681, wherein an interior volume of the fitting is configured to be reduced using a swaging method.

693. The fitting of claim 681, wherein the electrically insulating material comprises material substantially similar to electrical insulation in at least one of the two insulated conductors.

694. The fitting of claim 681, wherein at least one of the insulated conductors is configured to be used to heat a subsurface formation.

695. The fitting of claim 681, wherein the sleeve is configured to be placed over the end of the first insulated conductor and the end of the second insulated conductor.

696. The fitting of claim 681, wherein the core coupling is configured to tightly fit around the end of the core of the first insulated conductor and the end of the core of the second insulated conductor.

697. An insulated conductor heater, comprising:

an electrical conductor configured to produce heat when an electrical current is provided to the electrical conductor;

an electrical insulator at least partially surrounding the electrical conductor, wherein the electrical insulation comprises a resistivity that remains substantially constant, or increases, over time when the electrical conductor produces heat; and

an outer electrical conductor at least partially surrounding the electrical insulation layer.

698. The heater of claim 697, wherein the heater is configured to be located in an opening in a subsurface formation.

699. The heater of claim 697, wherein the heater is configured to be located in an opening in a subsurface formation and the heater is configured to provide heat to at least a portion of the subsurface formation.

700. An insulated conductor heater, comprising:

an electrical conductor configured to produce heat when an electrical current is provided to the electrical conductor;

an electrical insulator at least partially surrounding the electrical conductor, wherein the electrical insulation comprises one or more blocks of insulation, and wherein the blocks of insulation comprise a resistivity that remains substantially constant, or increases, over time when the electrical conductor produces heat; and

an outer electrical conductor at least partially surrounding the electrical insulation layer.

701. The heater of claim 700, wherein the blocks of insulation comprise purified magnesium oxide blocks.

702. The heater of claim 700, wherein the blocks of insulation are formed from powdered magnesium oxide.

703. A method for forming at least part of an insulated conductor, comprising:

placing a first partially cylindrical portion of an insulated conductor between at least part of an elongated, cylindrical inner electrical conductor and at least part of a partially cylindrical, elongated outer electrical conductor;

placing at least one additional partially cylindrical portion of the insulated conductor between at least part of the inner electrical conductor and at least part of the partially formed outer electrical conductor, wherein the additional portion of the insulated conductor is

horizontally displaced from the first portion of the insulated conductor along a length of the part of the elongated outer electrical conductor; and

moving the additional portion of the insulated conductor towards the first portion of the insulated conductor with a selected amount of force such that the additional portion of the insulated conductor and the first portion of the insulated conductor are substantially compressed against each other.

704. The method of claim 703, further comprising mechanically or pneumatically moving the additional portion of the insulated conductor towards the first portion of the insulated conductor with the selected amount of force.

705. The method of claim 703, further comprising forming a substantially cylindrical, elongated outer electrical conductor from the part of the outer electrical conductor comprising the insulated conductor portions after moving the additional portion of the insulated conductor towards the first portion of the insulated conductor.

706. The method of claim 705, further comprising forming at least part of the insulated conductor after forming the substantially cylindrical, elongated outer electrical conductor.

707. The method of claim 703, further comprising forming at least part of the partially cylindrical, elongated outer electrical conductor from an elongated strip of an electrically conductive material.

708. The method of claim 703, further comprising locating the part of the elongated, cylindrical inner electrical conductor in the part of the partially cylindrical, elongated outer electrical conductor.

709. A method for installing two or more heaters in a subsurface formation, comprising:

providing a spool comprising a substantially helical configuration of two or more heaters that have been spooled on the spool;

unspooling the helical configuration of heaters from the spool; and

installing the helical configuration of heaters into an opening in a subsurface formation.

710. The method of claim 709, wherein the subsurface formation comprises a hydrocarbon containing formation.

711. The method of claim 709, wherein the heaters are insulated conductor heaters.

712. The method of claim 709, wherein the helical configuration of heaters comprises a pitch between about 5% and about 10%.

713. The method of claim 709, further comprising varying the pitch of the helical configuration of heaters along a length of the heaters.

714. The method of claim 709, further comprising twisting the two or more heaters using a twist head.

715. The method of claim 709, further comprising twisting two or more heaters as the heaters are spooled onto the spool.

716. The method of claim 709, further comprising twisting two or more heaters as the heaters are spooled onto the spool into a substantially helical configuration.

717. The method of claim 709, further comprising spooling the helical configuration of heaters onto the spool.

718. A system configured to heat a subsurface formation, comprising:

an elongated heater at least partially located in an opening in a hydrocarbon containing layer of the formation, the opening extending from the surface of the formation through an overburden section of the formation and into the hydrocarbon containing layer of the formation, the elongated heater comprising:

an electrical conductor;

an insulation layer at least partially surrounding the electrical conductor; and

an electrically conductive sheath at least partially surrounding the insulation layer;

wherein the elongated heater tapers from a larger thickness at a first end of the heater to a smaller thickness at a second end of the heater, the first end being at or near the junction between the overburden section and the hydrocarbon containing layer and the second end being further into the hydrocarbon containing layer.

719. The system of claim 718, wherein the tapered thickness in the elongated heater is provided by tapering the thickness of the insulation layer from the first end to the second end of the heater.

720. A heater configured to heat a subsurface formation, comprising:

an electrical conductor;

a semiconductor layer at least partially surrounding the electrical conductor;

an insulation layer at least partially surrounding the electrical conductor; and

an electrically conductive sheath at least partially surrounding the insulation layer.

721. The heater of claim 720, wherein the semiconductor layer is located inside the insulation layer.

722. The heater of claim 720, wherein the semiconductor layer is at least partially surrounded by the insulation layer.

723. The heater of claim 720, wherein the insulation layer at least partially surrounds the semiconductor layer.

724. The heater of claim 720, wherein the semiconductor layer is configured to reduce the electrical field in the electrical conductor during use.

725. The heater of claim 720, wherein the semiconductor layer is configured to reduce electrical stresses on the insulation layer during use.

726. The heater of claim 720, wherein the insulation layer comprises magnesium oxide.

727. The heater of claim 720, wherein the semiconductor layer has a higher dielectric constant than the insulation layer.

728. The heater of claim 720, wherein the semiconductor layer comprises a plurality of semiconductor layers with varying dielectric constants.

729. The heater of claim 720, further comprising an additional semiconductor layer on an opposite side of the insulation layer from the semiconductor layer.

730. The heater of claim 720, wherein the heater is configured to provide resistive heat output to heat at least a portion of the subsurface formation.

731. The heater of claim 720, wherein the heater is located in a hydrocarbon containing layer in the subsurface formation, and the heater is configured to provide resistive heat output to heat at least a portion of the subsurface formation to mobilize hydrocarbons in the layer.

732. The heater of claim 720, wherein the heater is located in a hydrocarbon containing layer in the subsurface formation, and the heater is configured to provide resistive heat output to heat at least a portion of the subsurface formation to pyrolyze hydrocarbons in the layer.

733. A system for treating a subsurface formation, comprising:

a first wellbore at least partially located in a hydrocarbon containing formation, wherein the first wellbore comprises a substantially horizontal or inclined portion in a hydrocarbon containing layer in the formation;

a first conductor at least partially positioned in the substantially horizontal or inclined portion of the first wellbore, wherein the first conductor comprises electrically conductive material;

at least one conductive material substantially surrounding the first conductor in the substantially horizontal or inclined portion of the first wellbore;

a second conductor located in the hydrocarbon containing layer in the formation, wherein the second conductor comprises a substantially horizontal or inclined portion in the hydrocarbon containing layer in the formation;

at least one conductive material substantially surrounding the substantially horizontal or inclined portion of the second conductor; and

a power supply coupled to the first conductor, the power supply configured to electrically excite the electrically conductive materials of the first conductor such that current flows between the electrically conductive materials in the first conductor, through at least a portion of the

formation, to the second conductor, and the current resistively heats at least a portion of the formation between the two conductors.

734. The system of claim 733, wherein the conductive material comprises graphite.

735. The system of claim 733, wherein the conductive material comprises conductive cement.

736. A system for treating a subsurface formation, comprising:

a first wellbore at least partially located in a hydrocarbon containing formation, wherein the first wellbore comprises a substantially horizontal or inclined portion in a hydrocarbon containing layer in the formation;

a first conductor at least partially positioned in the substantially horizontal or inclined portion of the first wellbore, wherein the first conductor comprises electrically conductive material, and wherein at least a portion of the first conductor positioned in the substantially horizontal or inclined portion of the first wellbore comprises copper coupled to the electrically conductive material, the copper tapering from a larger thickness at a first end of the portion to a smaller thickness at a second end of the portion, the first end being closer to an overburden section of the first wellbore than the second end; and

a power supply coupled to the first conductor, the power supply configured to electrically excite the electrically conductive materials of the first conductor such that current flows between the electrically conductive materials in the first conductor, through at least a portion of the formation, to a second conductor located in the hydrocarbon containing layer in the formation, and the current resistively heats at least a portion of the formation between the two conductors.

737. The system of claim 736, further comprising:

a second wellbore at least partially located in the hydrocarbon containing formation; and

the second conductor at least partially positioned in a portion of the second wellbore in the hydrocarbon containing layer in the formation, wherein the second conductor comprises electrically conductive material.

738. The system of claim 736, further comprising a lead-in conductor coupled to the first conductor, wherein the lead-in conductor is located in the overburden section of the first wellbore.

739. The system of claim 738, further comprising copper coupled to at least a portion of the lead-in conductor, wherein the copper comprises a substantially constant thickness along a length of the lead-in conductor.

740. The system of claim 736, wherein at least a portion of the second conductor is substantially horizontal or inclined in the formation.

741. The system of claim 736, wherein at least a portion of the first and second conductors are substantially parallel to each other.

742. The system of claim 736, wherein at least a portion of the first and second conductors are perforated.

743. The system of claim 736, wherein the electrically conductive material is carbon steel.

744. The system of claim 736, wherein the copper comprises heat treated copper.

745. The system of claim 736, wherein the copper comprises copper clad to the electrically conductive material.

746. A method for heating a hydrocarbon containing formation, comprising:

providing time-varying electrical current at a first frequency to an elongated electrical conductor located in the formation;

inducing electrical current flow in a ferromagnetic conductor with the time-varying electrical current at the first frequency, wherein the ferromagnetic conductor at least partially surrounds and at least partially extends lengthwise around the electrical conductor;

resistively heating the ferromagnetic conductor with the induced electrical current flow such that the ferromagnetic conductor resistively heats up to a first temperature, wherein the first temperature is at most about 300 °C;

allowing heat to transfer from the ferromagnetic conductor at the first temperature to at least a part of the formation;

vaporizing at least some water in the formation with the ferromagnetic conductor at the first temperature;

providing time-varying electrical current at a second frequency to the elongated electrical conductor;

inducing electrical current flow in the ferromagnetic conductor with the time-varying electrical current at the second frequency;

resistively heating the ferromagnetic conductor with the induced electrical current flow such that the ferromagnetic conductor resistively heats up to a second temperature, wherein the second temperature is above about 300 °C;

allowing heat to transfer from the ferromagnetic conductor at the second temperature to at least a part of the formation; and

mobilizing at least some hydrocarbons in the part of the formation with the ferromagnetic conductor at the second temperature.

747. A method of treating a subsurface formation, comprising:

circulating at least one molten salt through piping located in the formation to heat at least a portion of the formation and heat at least some hydrocarbons in the formation to at least a mobilization temperature of the hydrocarbons;

providing an oxidizing fluid to at least a portion of the piping; and

oxidizing coke formed in the piping.

748. A method of treating a subsurface formation, comprising:

circulating at least one molten salt through piping located in the formation to heat at least a portion of the formation and heat at least some hydrocarbons in the formation to at least a mobilization temperature of the hydrocarbons; and

locating a liner in and/or around at least a portion of the piping to inhibit hydrocarbons from entering the piping and contacting the molten salt.

749. A method of treating a subsurface formation, comprising:

circulating at least one molten salt through at least one conduit of a conduit-in-conduit heater located in the formation to heat at least some hydrocarbons in the formation to at least a mobilization temperature of the hydrocarbons;

producing at least some of the hydrocarbons from the formation;

assessing an electrical resistance of at least one of the conduits of the conduit-in-conduit heater; and

assessing a presence of a leak in at least one of the conduits based on the assessed resistance.

750. A method of treating a subsurface formation, comprising:

circulating at least one molten salt through at least one conduit of a conduit-in-conduit heater located in the formation to heat at least some hydrocarbons in the formation to at least a mobilization temperature of the hydrocarbons;

producing at least some of the hydrocarbons from the formation;

circulating an inert gas with the molten salt; and

assessing a presence of a leak in at least one of the conduits by assessing a presence of the inert gas inside the walls of at least one of the conduits.

751. A method of treating a subsurface formation, comprising:

circulating at least one molten salt through piping in the formation to heat at least some hydrocarbons in the formation to at least a mobilization temperature of the hydrocarbons;

producing at least some of the hydrocarbons from the formation;

terminating circulation of the molten salt in the piping after a selected amount of hydrocarbons have been produced from the formation; and

providing a compressed gas into the piping to remove molten salt remaining in the piping.

752. A method of heating a subsurface formation, comprising:

circulating a heated heat transfer fluid comprising a carbonate molten salt through piping positioned in at least two of a plurality of wellbores using a fluid circulation system, wherein the plurality of wellbores are positioned in a formation; and

heating at least a portion of the formation.

753. The method of claim 752, wherein the carbonate molten salt comprises sodium, potassium and lithium carbonate salts.

754. The method of claim 752, wherein the carbonate molten salt has a melting point of at least 300 °C.

755. The method of claim 752, wherein the carbonate molten salt has a melting point of about 600 °C.

756. The method of claim 752, wherein the carbonate molten salt comprises a eutectic mixture of sodium, potassium and lithium carbonate salts.

757. A method of heating a subsurface formation, comprising:

circulating a heated heat transfer fluid through piping positioned in at least two of a plurality of wellbores using a fluid circulation system, wherein the plurality of wellbores are positioned in a formation;

heating at least a first portion of the formation;

allowing at least a portion of the heated heat transfer fluid to flow through openings in the piping into the formation;

cooling at least a portion of the heated heat transfer fluid in the formation to form a permeable heater, wherein at least a portion of the permeable heater surrounds a portion of the piping; and

heating at least a second portion of the formation, wherein the second portion is adjacent the permeable heater.

758. The method of claim 757, wherein the heated heat transfer fluid comprises carbonate molten salts.

759. The method of claim 757, wherein the heated heat transfer fluid comprises carbonate molten salts having a melting point of at least 390 °C.

760. The method of claim 757, further comprising heating the heat transfer fluid using the formation heated by another heat transfer fluid.

761. The method of claim 757, further comprising heating the heat transfer fluid using the formation heated by air, superheated steam, synthetic heat transfer fluid, or mixtures thereof.

762. The method of claim 757, wherein openings in the portion of the piping are prefabricated.

763. The method of claim 757, wherein the permeable heater has a diameter of at least 2 times the diameter of the piping.

764. The method of claim 757, wherein the piping positioned in at least two of a plurality of wellbores comprises an abandoned circulation system.

765. A method for treating a hydrocarbon containing formation, comprising:

injecting a composition comprising solid salts in a section of the formation;

providing heat from one or more heaters to the portion of the formation to heat the composition to about or above a melting point of the solid salts in the composition; and

melting at least a portion of the solid salts to form a molten salt and create fractures in the section.

766. The method of claim 765, further comprising providing at least one heater to at least some of the fractures in the section.

767. The method of claim 765, further comprising injecting fluid in at least some of the fractures in the section.

768. The method of claim 765, wherein fractures are created by expansion of the solid salt during melting.

769. The method of claim 765, further comprising contacting at least a portion of the heated composition with at least some hydrocarbons to cause an increase in pressure in the section to create fractures in the formation.

770. A method of treating a hydrocarbon containing formation, comprising:

providing heat from a plurality of heaters to a section of the hydrocarbon containing formation;

controlling the heat from the plurality of heaters such that an average temperature in at least a majority of a first portion of the section is above a pyrolyzation temperature;

providing heat from the plurality of heaters to a second portion substantially above the first portion of the section after heating the first portion for a selected time;

controlling the heat from the plurality of heaters such the an average temperature in the second portion is sufficient to allow the second portion to expand into the first portion; and

producing hydrocarbons from the formation.

771. The method of claim 770, wherein a depth of the first portion is about 400 m to about 750 m from the surface of the formation.

772. The method of claim 770, wherein a depth of the second portion is about 150 m to about 400 m from the surface of the formation.

773. The method of claim 770, wherein a depth of the first portion is about 400 m from the surface of the formation and a depth of the second portion is about 150 m from the surface of the formation.

774. The method of claim 770, wherein an initial porosity of the first portion is different than the initial porosity of the second portion.

775. The method of claim 770, wherein heat from the plurality of heaters heats the first portion to a temperature of about 230 °C.

776. The method of claim 770, wherein the selected time ranges from about nine months to about twenty-four months.

777. The method of claim 770, wherein heat from the plurality of heaters heats the second portion to a temperature above a pyrolyzation temperature.

778. The method of claim 770, wherein heat from the plurality of heaters heats the second portion to a temperature of from about 200 °C to about 370 °C.

779. The method of claim 770, wherein heat from the plurality of heaters mobilizes hydrocarbons in the first portion.

780. The method of claim 770, wherein the produced hydrocarbons comprise pyrolyzed hydrocarbon from the second portion.

781. The method of claim 770, wherein hydrocarbons are produced from the first portion.

782. The method of claim 770, wherein hydrocarbons are produced from the first portion and the hydrocarbons comprise pyrolyzed hydrocarbons from the second portion.

783. The method of claim 770, wherein expansion of the second portion into the first portion inhibits fracturing of the overburden.

784. The method of claim 770, wherein controlling heat from the plurality of heaters heats the first section to a pyrolysis temperature after at least some of the second portion has expanded into the first portion.

785. A method of treating a hydrocarbon containing formation in situ, comprising:

providing heat from a plurality of heaters to a section of the hydrocarbon containing formation;

allowing heat from the plurality of heaters to transfer to a first portion such that at least a majority of a first portion of the section at a depth of about 400 m below the surface is heated to a pyrolyzation temperature; and

allowing heat from the plurality of heaters to transfer to a second portion at a depth of about 150 m from the surface of the formation and substantially above the first portion after heating the first portion for a selected time;

wherein providing heat to the second portion after heating the first portion inhibits geomechanical expansion of the overburden above the second portion of the formation.

786. The method of claim 785, wherein a pyrolyzation temperature ranges from about 230 °C to about 370 °C.

787. The method of claim 785, wherein the selected time ranges from about nine months to about twenty-four months.

788. The method of claim 785, wherein heat from the plurality of heaters heats the second portion to a temperature above a pyrolyzation temperature.

789. The method of claim 785, wherein transfer of heat to the second portion heats the second portion at a rate sufficient to allow expansion of the second portion into the first portion.

790. The method of claim 785, wherein heat from the plurality of heaters mobilizes hydrocarbons in the first portion and the hydrocarbons produced from the formation comprise mobilized hydrocarbon from the first portion.

791. The method of claim 785, wherein the produced hydrocarbons comprise pyrolyzed hydrocarbon from the second portion.

792. The method of claim 785, wherein hydrocarbons are produced from the first portion.

793. The method of claim 785, wherein hydrocarbons are produced from the first portion and the hydrocarbons comprise pyrolyzed hydrocarbons from the second portion.

794. A method of producing methane from a hydrocarbon containing formation, comprising:

providing heat the formation from a plurality of heaters located in the formation, wherein one or more of the heaters comprise one or more insulated electrical conductors;

allowing the heat to transfer from the heaters to at least a portion of the formation comprising methane;

maintaining an average temperature in the portion of the formation below a pyrolyzation temperature of hydrocarbons in the formation comprising methane; and

removing methane from the portion of the formation.

795. The method of claim 794, wherein the hydrocarbon containing formation comprises oil shale.

796. The method of claim 794, further comprising removing hydrocarbons having a carbon number between 1 and 5 from the portion of the formation.

797. The method of claim 794, wherein the portion of the formation comprises coal.

798. The method of claim 794, further comprising providing a barrier around the portion of the formation.

799. The method of claim 794, wherein an average temperature in the portion of the formation is below 230 °C.

800. The method of claim 794, wherein the portion of the formation comprises a deep coal seam.

801. A method of producing methane from a hydrocarbon containing formation, comprising:

providing heat to a first section the formation from a plurality of heaters located in the formation, wherein one or more of the heaters comprise one or more insulated electrical conductors;

allowing the heat to transfer from the heaters to the first section of the formation;

producing hydrocarbons from the first section;

extending one or more heaters from the first section into a second section of the formation, wherein the second section of the formation comprising methane;

maintaining an average temperature in the second section of the formation below a pyrolyzation temperature of hydrocarbons in the formation comprising methane; and

removing methane from the portion of the formation.

802. The method of claim 801, wherein the first section of the formation comprises oil shale.

803. The method of claim 801, wherein the second section of the formation comprises coal.

804. The method of claim 801, wherein the second section of the formation comprises a deep coal seam.

805. The method of claim 801, wherein the first section of the formation is an oil shale layer and the second section of the formation is substantially below the first section of the formation and the second section of the formation comprises coal.

806. The method of claim 801, wherein an average temperature in the second section of the formation is below 230 °C.

807. The method of claim 801, wherein an average temperature in the second section ranges from 30 °C to 40 °C.

808. The method of claim 801, further comprising removing hydrocarbons having a carbon number between 1 and 5 from the second section of the formation.

809. A method of treating a hydrocarbon containing formation, comprising:

providing heat to a section of the hydrocarbon containing formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the section;

producing formation fluid from the formation;

assessing a P-value of the at least a portion of the formation fluid produced from the formation; and

adjusting an asphaltene content of the hydrocarbons in the section of the formation when the assessed P-value of the portion of the produced hydrocarbons is at a selected value, wherein P-value is determined using ASTM Method D7060.

810. The method of claim 809, wherein the assessed P-value is less than about 1.5 or less than about 1.0.

811. The method of claim 809, wherein adjusting an asphaltene content of the hydrocarbons in the section comprises providing a deasphalting fluid to the section of the formation, the deasphalting fluid comprising hydrocarbons having a boiling range distribution between 35 °C and 260 °C at 0.101 MPa, and contacting the deasphalting fluid with the hydrocarbons in the section to remove at least a portion of asphaltenes from the hydrocarbons.

812. The method of claim 809, wherein adjusting the asphaltene content of the hydrocarbons in the section comprises providing a deasphalting fluid comprising hydrocarbons having a boiling range distribution between 35 °C and 260 °C at 0.101 MPa to the first section of the formation, and wherein deasphalting fluid has been produced from an in situ heat treatment process, and contacting the deasphalting fluid with the hydrocarbons in the section to remove at least a portion of asphaltenes from the hydrocarbons.

813. The method of claim 809, wherein adjusting the asphaltene content of the hydrocarbons in the section comprises providing bitumen to the first section of the formation to increase an amount of heavy hydrocarbons in the section of the formation.

814. The method of claim 809, wherein adjusting the asphaltene content of the hydrocarbons in the section comprises providing hydrocarbons having a boiling range distribution between 35 °C and 260 °C at 0.101 MPa, bitumen, or mixtures thereof to the section of the formation.

815. The method of claim 809, wherein adjusting the asphaltene content of the hydrocarbons in the section comprises controlling formation conditions to allow bitumen from another section of the formation to flow into the section of the formation.

816. The method of claim 809, further comprising mobilizing hydrocarbons in the section after adjusting an asphaltene content, and producing at least a portion of the mobilized hydrocarbons from another section of the formation, wherein at least a portion of the mobilized hydrocarbons produced from the other section have a P-value of about 1.5.

817. A method of treating a hydrocarbon formation, comprising:

providing heat to a section of the hydrocarbon formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the section to a selected temperature;

producing hydrocarbons from the section of the formation;

assessing a H/C molar ratio of asphaltenes in at least a portion of the hydrocarbons produced from the formation; and

adjusting an asphaltenes content of the hydrocarbons in the section of the formation when the assessed H/C molar ratio of the asphaltenes in the portion of produced hydrocarbons reaches a selected value.

818. The method of claim 817, wherein the selected temperature is at least 230 °C.

819. The method of claim 817, wherein the selected H/C molar ratio is less than about 1.

820. The method of claim 817, wherein adjusting the asphaltenes content inhibits a net reduction of the assessed H/C molar ratio over time.

821. The method of claim 817, wherein adjusting the asphaltenes content comprises allowing hydrocarbons having a boiling point of at least 537 °C to ingress into the section from a different section of the hydrocarbon formation.

822. The method of claim 817, wherein adjusting the asphaltenes content comprises injecting a deasphalting fluid, the deasphalting fluid comprising hydrocarbons having a boiling point less than about 260 °C into the first section.

823. The method of claim 817, further comprising mobilizing hydrocarbons in the section after adjusting the asphaltene content.

824. The method of claim 817, further comprising mobilizing hydrocarbons in the section after adjusting the asphaltene content, and producing at least a portion of the mobilized hydrocarbons from another section of the formation, wherein at least a portion of the mobilized hydrocarbons produced from the other section have a H/C molar ratio of greater than 1.1.

825. A method of treating a hydrocarbon formation, comprising:

providing heat to a section of the hydrocarbon formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the section to a selected temperature;

producing hydrocarbons from the section of the formation;

assessing a volume ratio of naphtha/kerosene to hydrocarbons having a boiling point of greater than 520 °C in at least a portion of the hydrocarbons produced from the formation;

adjusting volume ratio of naphtha/kerosene to heavy hydrocarbons in the section of the formation when the assessed volume ratio of naphtha/kerosene to hydrocarbons having a boiling point of greater than 520 °C in the portion of produced hydrocarbons reaches a selected value; and

mobilizing hydrocarbons in the formation.

826. The method of claim 825, wherein the selected temperature is at least 230 °C.

827. The method of claim 825, wherein the selected value is greater than about 10.

828. The method of claim 825, wherein adjusting the volume ratio of naphtha/kerosene to heavy hydrocarbons inhibits a net reduction of a weight percentage of asphaltenes over time.

829. The method of claim 825, wherein adjusting the volume ratio of naphtha/kerosene to heavy hydrocarbons comprises allowing hydrocarbons having a boiling point of at least 520 °C and/or bitumen to flow into the section from a different section of the hydrocarbon formation.

830. The method of claim 825, wherein adjusting the volume ratio of naphtha/kerosene to heavy hydrocarbons comprises injecting hydrocarbons into the first section, at least a portion of the injected hydrocarbons having a boiling point less than about 260 °C.

831. The method of claim 825, further comprising mobilizing hydrocarbons in the section after adjusting a volume ratio of naphtha/kerosene to heavy hydrocarbons.

832. The method of claim 825, further comprising mobilizing hydrocarbons in the section after adjusting a volume ratio of naphtha/kerosene to heavy hydrocarbons, and producing at least a portion of the mobilized hydrocarbons from another section of the formation, wherein at least a portion of the produced mobilized hydrocarbons exhibit enhanced stability.

833. A method of treating a hydrocarbon formation, comprising:

providing heat to a section of the formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the section to a selected temperature to generate an in situ deasphalting fluid in the section, wherein the in situ deasphalting fluid comprises hydrocarbons having a boiling range distribution between 35 °C and 260 °C at 0.101 MPa;

contacting at least a portion of the in situ deasphalting fluid with hydrocarbons in the section to remove at least some asphaltenes from the hydrocarbons in the section, wherein the a majority of the hydrocarbons in the section have a boiling point greater than 260 °C at 0.101 MPa; and

producing at least a portion of the deasphalted hydrocarbons from the formation.

834. The method of claim 833, wherein the in situ deasphalting fluid is generated by pyrolyzing at least a portion of heavy hydrocarbons in the section.

835. The method of claim 833, further comprising controlling a pressure of the section such that the in situ deasphalting fluid is present as a liquid in the section.

836. The method of claim 833, wherein a P-value of the deasphalted hydrocarbons is at least 1.

837. The method of claim 833, wherein sufficient in situ deasphalting fluid is generated such that at least 5:1 a volume ratio of in situ deasphalting fluid to heavy hydrocarbons in the section is maintained.

838. A method of treating a hydrocarbon formation, comprising:

providing heat to a section of the formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the section to a selected temperature to generate an in situ deasphalting fluid in the section, wherein the in situ deasphalting fluid comprises hydrocarbons having a boiling range distribution between 35 °C and 260 °C at 0.101 MPa;

changing a volume ratio of naphtha/kerosene to heavy hydrocarbons in the section by contacting at least a portion of the in situ deasphalting fluid with heavy hydrocarbons in the section; and

producing at least a portion of the deasphalted hydrocarbons from the formation.

839. A method of treating a hydrocarbon formation, comprising:

providing heat to a first section of a hydrocarbon layer in the formation from a plurality of heaters located in the first section of the formation;

allowing the heat to transfer from the heaters to the first section of the formation;

generating an in situ deasphalting fluid comprising hydrocarbons having a boiling range distribution between 35 °C and 200 °C at 0.101 MPa in the first section by heating hydrocarbons in the first section, wherein a majority of the hydrocarbons in the first section having a boiling point greater than 260 °C;

mobilizing at least a portion of the in situ deasphalting fluid through an upper portion of the first section to an upper portion of a second section of the formation;

contacting the in situ deasphalting fluid with hydrocarbons in the upper portion of the second section to remove at least a portion of the asphaltenes from the hydrocarbon in the upper portion of the second section, wherein a temperature of upper portion of the second section is less than the temperature of the upper portion of the first section; and

producing at least a portion of the deasphalted hydrocarbons from the formation.

840. The method of claim 839, wherein allowing heat to transfer raises the average temperature in a portion of the first section to a pyrolysis temperature.

841. The method of claim 839, wherein allowing heat to transfer heats the first section to an average temperature of about 230 °C.

842. The method of claim 839, wherein allowing heat to transfer raises the average temperature in a portion of the first section to a pyrolysis temperature and wherein generating the in situ deasphalting fluid comprises pyrolyzing at least a portion of heavy hydrocarbons in the first section to form the in situ deasphalting fluid.

843. The method of claim 839, further comprising controlling temperature and pressure in the first section to mobilize at least a portion of the in situ deasphalting fluid from a lower portion of the first section to the upper portion of the first section.

844. The method of claim 839, wherein a pressure in the second section of the formation is controlled such that substantially all of the in situ deasphalting fluid is present as a liquid.

845. The method of claim 839, wherein the majority of the asphaltenes removed from the hydrocarbons remain in the second section.

846. The method of claim 839, wherein the deasphalted hydrocarbons are produced from the second section of the formation.

847. The method of claim 839, wherein the deasphalted hydrocarbons are produced from a third section of the formation.

848. The method of claim 839, wherein the deasphalted hydrocarbons are produced from a third section of the formation substantially adjacent the second section of the formation.

849. The method of claim 839, wherein the produced deasphalted hydrocarbons are suitable for transportation.

850. The method of claim 839, wherein the produced deasphalted hydrocarbons have a P-value of at least 1.

851. The method of claim 839, further comprising producing at least some hydrocarbons from a portion lower than the upper portion of the second section, and allowing at least a portion of the in situ deasphalting fluid to drain to the lower portion of the second section.

852. The method of claim 839, further comprising producing at least some hydrocarbons from a portion lower than the upper portion of the second section, allowing at least a portion of the in situ deasphalting fluid to drain to the lower portion of the second section, contacting at least a portion of the in situ deasphalting fluid with hydrocarbons in the lower portion of the second section to remove asphaltenes from the hydrocarbons in the lower portion of the second section, and producing deasphalted hydrocarbons from the lower portion of the second section.

853. A method for treating a previously treated tar sands formation, comprising:

assessing the previously treated formation to identify one or more portions of the formation that have not been heated to a sufficient temperature to mobilize hydrocarbons by a previous treatment process;

locating one or more heaters in the identified portions;

providing heat to the identified portions from the heaters;

mobilizing at least some hydrocarbons in the identified portions; and

producing at least some hydrocarbons from the identified portions.

854. The method of claim 853, wherein the sufficient temperature is a mobilization temperature of hydrocarbons in the portions.

855. The method of claim 853, wherein the sufficient temperature is at most about 100 °C.

856. The method of claim 853, wherein the previous treatment process comprises a steam drive process.

857. The method of claim 853, wherein the previous treatment process comprises a steam drive process, and the steam drive process did not provide sufficient heat to raise the temperature

of one or more portions to mobilize hydrocarbons due to channeling of the steam in the formation.

858. The method of claim 853, wherein the previous treatment process comprises a steam drive process and/or an in situ heat treatment process.

859. The method of claim 853, wherein the previous treatment process comprises an in situ heat treatment process and heat provided by heaters from the in situ heat treatment process did not provide raise the temperature of the formation to the sufficient temperature to mobilize the hydrocarbons in the portions.

860. The method of claim 853, wherein assessing the formation comprises assessing properties of the formation using a 4D seismic technique.

861. The method of claim 853, further comprising providing heat sufficient to mobilize hydrocarbons in one or more of the identified portions.

862. The method of claim 853, further comprising providing a drive fluid to the identified portions after providing heat sufficient to mobilize hydrocarbons in the identified portions.

863. A method of treating a hydrocarbon containing formation, comprising:

providing heat to a section of the hydrocarbon containing formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the section to mobilize formation fluid, wherein the portion has a sulfur compound content of at least 1.3% by weight; and

producing mobilized formation fluid from the formation.

864. A method of treating a hydrocarbon containing formation, comprising:

providing heat to a section of the hydrocarbon containing formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the section to mobilize formation fluid, wherein the portion has a sulfur compound content of at least 1.3% by weight; and

producing mobilized formation fluid from the formation, wherein the formation fluid has a thiophene content of at least 10% by weight.

865. A method of treating a hydrocarbon containing formation, comprising:

providing heat from a plurality of heaters to at least a section of the formation;

allowing the heat to transfer from the heaters to a portion of the section, wherein the portion of the section is selected for heating using a bitumen weight percentage of at least a portion of the hydrocarbons in the portion of the section, and wherein at the portion of hydrocarbons comprise at least 20% by volume bitumen;

mobilizing at least some of the bitumen in the section; and

producing bitumen from the formation.

866. A method of treating a hydrocarbon containing formation, comprising:

providing heat from a plurality of heaters to a section of the formation;

allowing the heat to transfer from the heaters to mobilize at least some bitumen in a first portion of section, wherein the first portion is between the heaters and a first production wellbore;

producing a mixture from the first production wellbore, wherein the produced mixture comprises bitumen;

allowing the heat to transfer from the heaters to mobilize at least some liquid hydrocarbons in a second portion of the formation, wherein the second portion has a higher average temperature than an average temperature of the first portion; and

producing hydrocarbons from a third portion of the hydrocarbon formation, wherein the produced hydrocarbons comprise mobilized liquid hydrocarbons from the second portion; and wherein an average temperature of the third portion is less than an average temperature of the first section and the second section.

867. The method of claim 866, wherein the average temperature of the first portion is below about 280 °C.

868. The method of claim 866, wherein the average temperature of the first portion is below about 270°C.

869. The method of claim 866, wherein the average temperature of the second portion ranges from about 260°C to about 300 °C.

870. The method of claim 866, wherein the hydrocarbons are cold produced from the third portion.

871. The method of claim 866, wherein a majority of the produced mobilized liquid hydrocarbons from the third portions comprise hydrocarbons having a boiling range distribution between 343 °C and 538 °C.

872. The method of claim 866, further comprising increasing a pressure in one or more heater wellbores to mobilize at least some of the bitumen in the first portion and/or second portion towards the first production wellbore.

873. The method of claim 872, wherein the pressure in the first section is increased to a pressure below a fracture pressure of the first section.

874. The method of claim 872, further comprising providing a drive fluid to the second portion and/or third portion at a pressure sufficient to drive at least a portion of the bitumen in the second and/or third portions towards the first production wellbore.

875. The method of claim 872, further comprising providing a solvation fluid to the second portion and/or third portion, wherein at least a portion of the bitumen in the second and/or third portions is solvated and mobilizing the solvated bitumen towards the first production wellbore.

876. A method of treating a hydrocarbon containing formation, comprising:

providing heat from a plurality of heaters to a section of the formation;

allowing the heat to transfer from the heaters to a first portion and a second portion of the section, wherein the heaters are positioned between the first and second portions of the treatment area;

mobilizing at least some bitumen in the first portion;

producing hydrocarbons from a third portion of the section, wherein the produced hydrocarbons comprise mobilized hydrocarbons from a second portion between the first and third portions;

introducing a drive fluid in a wellbore positioned in the second portion and/or third portion after production of at least a portion of the mobilized hydrocarbons from the first portion;

increasing the pressure in the wellbore by introducing the drive fluid under pressure so that the drive fluid drives at least a portion of bitumen in the second portion towards the first portion; and

producing a mixture from the first portion, wherein the produced mixture comprises bitumen from the second portion.

877. The method of claim 876, wherein the drive fluid is water, carbon dioxide, hydrocarbons, or a mixture thereof.

878. The method of claim 876, wherein a temperature in the first portion and/or second portion in the formation is sufficient to pyrolyze at least a portion of the bitumen to form pyrolyzed hydrocarbons.

879. The method of claim 876, wherein increasing the pressure drives the bitumen through the third portion positioned between the first and second portions and wherein the third portion has an average temperature above the first and second portions.

880. The method of claim 876, wherein at least a portion of the bitumen in the third portion is pyrolyzed, and the produced mixture further comprises pyrolyzed hydrocarbons from the third portion.

881. The method of claim 876, wherein increasing the pressure in the wellbore by introducing the drive fluid under pressure is sufficient to drive the bitumen, but below a fracture pressure of the formation.

882. A method of treating a hydrocarbon containing formation, comprising:

providing heat from a plurality of heaters to a section of the formation;

allowing the heat to transfer from the heaters to a first portion and a second portion of the section, wherein the heaters are positioned between the first and second portions of the treatment area;

mobilizing at least some bitumen in the first portion;

producing hydrocarbons from a third portion of the section, wherein the produced hydrocarbons comprise mobilized hydrocarbons from a second portion between the first and third portions and wherein an average temperature in the third portion is less than an average temperature in the first and second portions;

providing a solvation fluid to the second portion and/or third portion after production of at least a portion of the mobilized hydrocarbons from the first portion;

solvating at least a portion of the bitumen in the second portion and/or third portion; and

mobilizing at least a portion of the solvated bitumen towards the first portion.

883. The method of claim 882, wherein the solvation fluid comprises carbon dioxide.

884. The method of claim 882, wherein the solvation fluid comprises hydrogen sulfide.

885. The method of claim 882, wherein the solvation fluid comprises carbon disulfide.

886. The method of claim 882, wherein the solvation fluid comprises one or more thiophenes.

887. The method of claim 882, wherein the solvation fluid comprises one or more pyrroles.

888. The method of claim 882, wherein the solvation fluid comprises hydrocarbons produced from an in situ heat treatment process.

889. The method of claim 882, further comprising producing a mixture from the first portion, wherein the produced mixture comprises bitumen from the second portion and/or third portion.

890. A method of treating a hydrocarbon containing formation, comprising:

providing heat to a first section of the hydrocarbon containing formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the first section to mobilize formation fluid;

maintaining an average temperature in a second section of the formation below a pyrolysis temperature of hydrocarbons in the second section, wherein the second section comprises inorganic sulfur compounds; and

producing mobilized formation fluid from the formation.

891. The method of claim 890, wherein the first section is substantially above the second section.

892. The method of claim 890, wherein the first section is substantially below the second section.

893. The method of claim 890, wherein the first section is substantially vertical relative to the second section.

894. The method of claim 890, wherein the inorganic sulfur compounds comprises iron sulfide compounds.

895. The method of claim 890, wherein the inorganic sulfur compounds comprises pyritic sulfur.

896. The method of claim 890, wherein at least one of the heaters is substantially vertical in the first and second sections, and allowing transfer of heat comprises inhibiting heat transfer from at least a portion of the heater in the second section to the formation.

897. The method of claim 890, wherein the heaters in the first section are substantially horizontal.

898. The method of claim 890, wherein an average temperature of the second section is less than 230 °C.

899. A method of treating a hydrocarbon containing formation, comprising:

providing heat to a first section of the hydrocarbon containing formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the first section to mobilize hydrocarbons in the section, wherein the mobilized hydrocarbons comprises mercury;

mobilizing at least a portion of the hydrocarbons in the first section towards a second section comprising one or more inorganic sulfur compounds; and

contacting at least a portion of the pyrolyzed formation fluid comprising mercury and/or mercury compounds with at least a portion of the inorganic sulfur compounds in the second section to remove at least a portion of the mercury and/or mercury compounds from the mobilized hydrocarbons.

900. The method of claim 899, wherein one or more of the inorganic sulfur compound comprises pyrite.

901. The method of claim 899, wherein one or more of the inorganic sulfur compound comprises troilite.

902. The method of claim 899, wherein the first section is substantially horizontal relative to the second section.

903. The method of claim 899, wherein the first section is substantially vertical relative to the second section.

904. The method of claim 899, wherein an average temperature of the second section is below a pyrolysis temperature.

905. The method of claim 899, wherein the mobilized hydrocarbons comprises hydrocarbon gases.

906. The method of claim 899, further comprising producing hydrocarbons from a third section of the formation; wherein the produced hydrocarbons comprise hydrocarbons mobilized from the first section and the produced hydrocarbons contain less mercury, on a weight percent, than mobilized hydrocarbons in the first section.

907. The method of claim 899, wherein contact of the mobilized hydrocarbons with the inorganic sulfur compound removes substantially all of the mercury from the mobilized hydrocarbons; and producing hydrocarbons from the formation, wherein the produced hydrocarbons comprise substantially none or no mercury.

908. The method of claim 899, wherein at least one of the inorganic sulfur compounds comprises pyrite, and the method further comprises heating the second section to a temperature sufficient to convert at least some of the pyrite to troilite.

909. A method of treating a hydrocarbon containing formation, comprising:

providing heat to a first section of the hydrocarbon containing formation from a plurality of heaters located in the formation;

allowing the heat to transfer from the heaters to heat a portion of the first section to mobilize formation fluid;

maintaining an average temperature in a second section of the formation below a pyrolysis temperature of hydrocarbons in the second section, wherein the second section comprises inorganic nitrogen compounds; and

producing mobilized formation fluid from the formation.

910. The method of claim 909, wherein the inorganic nitrogen compounds comprises ammonia.

911. The method of claim 909, wherein the inorganic nitrogen compounds comprise ammonia feldspar.

912. A method for treating a formation containing dolomite and hydrocarbons, comprising:

treating least a portion of the formation containing dolomite and hydrocarbons using an in situ heat treatment process;

mobilizing at least a portion of the hydrocarbons in the formation;

producing at least a portion of the hydrocarbons from the formation;

injecting high pressure carbon dioxide and/or steam in the portion of the formation; and

forming dolomite and/or other mineral compounds in the formation.

913. The method of claim 912, further comprising cooling the mineral compounds to solidify the mineral compounds, and forming a barrier to a flow of formation fluid in or out of the formation.

914. The method of claim 912, wherein at least a portion of the high pressure carbon dioxide is produced from heating of the dolomite in the formation.

915. A method of establishing a double barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of first barrier wells in the formation;

using the at least a portion of the plurality of first barrier wells to form a first barrier around at least a portion of the subsurface treatment area;

forming a plurality of second barrier wells in the formation;

using the at least a portion of the plurality of second barrier wells to form a second barrier around the first barrier, wherein a space exists between the first barrier and the second barrier; and

inhibiting one or more portions of the first barrier and second barrier from forming a single combined barrier.

916. The method of claim 915, wherein the first barrier wells are freeze wells.

917. The method of claim 915, wherein the second barrier wells are freeze wells.

918. The method of claim 915, further comprising injecting fluid in the space between the first barrier and the second barrier.

919. The method of claim 915, further comprising injecting salinated water in the space between the first barrier and the second barrier.

920. The method of claim 915, further comprising injecting water in the space between the first barrier and the second barrier.

921. The method of claim 915, further comprising providing heat to the space between the first barrier and the second barrier.

922. The method of claim 915, further comprising:

forming a plurality of heater wells in the space between the first barrier and the second barrier; and

providing heat to the space between the first barrier and the second barrier.

923.The method of claim 915, further comprising joining the first barrier and/or the second barrier with one or more substantially impermeable zones.

924.The method of claim 915, further comprising monitoring at least a portion of the space between the first barrier and the second barrier to monitor the integrity of the first barrier and/or the second barrier.

925.The method of claim 915, further comprising forming one or more barrier segments between the first barrier and the second barrier to section the space between the first barrier and the second barrier into different sections.

926.The method of claim 925, further comprising monitoring one or more of the sections to monitor the integrity of the first barrier and/or the second barrier.

927.The method of claim 915, further comprising heating hydrocarbons in the subsurface treatment area.

928.The method of claim 915, further comprising reducing salinity of water in the space between the first barrier and the second barrier.

929.The method of claim 915, wherein the first barrier and/or the second barrier comprises a frozen barrier formed using freeze wells to freeze at least a portion of the subsurface area.

930.The method of claim 915, comprising first forming the first barrier by freezing one or more subsurface areas, and then forming the second barrier using equipment initially used to form the first barrier.

931.The method of claim 915, comprising first forming the second barrier by freezing subsurface areas, and then forming the first barrier using equipment initially used to form the second barrier.

932. A barrier system for a subsurface treatment area in a hydrocarbon containing formation, comprising:

a first barrier formed around at least a portion of the subsurface treatment area, the first barrier configured to inhibit fluid from exiting or entering the subsurface treatment area;

a second barrier formed around at least a portion of the first barrier, wherein a space exists between the first barrier and the second barrier; and

an injection system which inhibits, during use, one or more portions of the first barrier and second barrier from forming a single combined barrier.

933. The system of claim 932, wherein the first barrier is formed from a plurality of first barrier wells in the formation.

934. The system of claim 932, wherein the first barrier is formed from a plurality of first barrier wells in the formation, and wherein the first barrier wells are freeze wells.

935. The system of claim 932, wherein the second barrier is formed from a plurality of second barrier wells in the formation.

936. The system of claim 932, wherein the second barrier is formed from a plurality of second barrier wells in the formation, and wherein the second barrier wells are freeze wells.

937. The system of claim 932, wherein the injection system inject fluids, during use, in the space between the first barrier and the second barrier.

938. The system of claim 932, wherein the injection system injects salinated water, during use, in the space between the first barrier and the second barrier.

939. The system of claim 932, wherein the injection system injects water, during use, in the space between the first barrier and the second barrier.

940. The system of claim 932, wherein the injection system provides heat to the space between the first barrier and the second barrier.

941. The system of claim 932, further comprising a plurality of heater wells in the space between the first barrier and the second barrier, wherein at least a portion of the heater wells provide heat to the space between the first barrier and the second barrier.

942.The system of claim 932, wherein the first barrier and/or the second barrier are joined with one or more substantially impermeable zones.

943.The system of claim 932, further comprising at least one monitor well in the space between the first barrier and the second barrier, wherein the monitor well is configured to monitor integrity of the first barrier and/or the second barrier.

944.The system of claim 932, further comprising one or more monitor wells positioned in the space between the first barrier and the second barrier, wherein an opening of a first monitor well of the monitor wells is at a depth corresponding to a first aquifer zone, and wherein an opening of a second monitor well of the monitor wells is at a depth corresponding to a second aquifer zone.

945.The system of claim 932, further comprising a first monitor well in the space between the first barrier and the second barrier, and a second monitor well located outside of the second barrier, wherein the first monitor well and the second monitor well are configured to monitor integrity of the second barrier.

946.The system of claim 932, further comprising barrier segments formed between the first barrier and the second barrier, wherein the barrier segments are configured to section the space between the first barrier and the second barrier.

947.The system of claim 946, further comprising a first monitor well in one or more of the sections to monitor, during use, the integrity of the first barrier and/or the second barrier.

948.The system of claim 932, wherein the first barrier and/or the second barrier comprises a frozen barrier formed using freeze wells to freeze at least a portion of the subsurface area.

949. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of barrier freeze wells in the formation;

injecting water in at least some of the plurality of barrier freeze wells, wherein at least a portion of the injected water is supplied from a natural source of water;

assessing changes in availability of the natural source of water; and

using the at least a portion of the plurality of barrier freeze wells to form a barrier around at least a portion of the subsurface treatment area.

950. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of substantially horizontal barrier freeze wells in the formation;

injecting water in at least some of the plurality of horizontal barrier freeze wells to form an at least substantially horizontal channel at least partially through the treatment area;

forming a plurality of substantially vertical barrier freeze wells in the formation;

injecting water in at least some of the plurality of vertical barrier freeze wells to form an at least substantially vertical barrier;

diverting at least a portion of a flow of water in the formation through the substantially horizontal channel while the substantially vertical barrier is being formed; and

extending the barrier such that the water flow is inhibited from entering the substantially horizontal channel and the treatment area.

951. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of barrier freeze wells in the formation;

injecting water in one or more first freeze wells to form at least a first portion of the barrier;

injecting water in one or more second freeze wells to form at least a second portion of the barrier after formation of the first portion; and

injecting water in one or more third freeze wells to form at least a third portion of the barrier after formation of the second portion;

wherein the barrier is oriented at an angle to a flow of water in the formation.

952. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of barrier freeze wells in the formation, wherein substantially all barrier freeze wells or a grouping of barrier freeze wells are offset from one another such that at least two parallel lines of barrier freeze wells are formed; and

injecting water in one or more first freeze wells to form at least a portion of the barrier around at least a portion of the subsurface treatment area such that at least the portion of the barrier is corrugated.

953. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of barrier freeze wells in the formation;

increasing the pressure in at least a portion of the formation adjacent to at least a portion of the plurality of barrier wells such that at least the portion fractures and permeability of the portion is increased; and

injecting water in one or more barrier freeze wells to form at least a portion of the barrier around at least a portion of the subsurface treatment area.

954. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

analyzing the formation to assess optimal positioning of potential barriers;

forming a plurality of barrier freeze wells in the formation;

injecting water in one or more barrier freeze wells; and

injecting super cooled fluids to form at least a portion of the barrier around at least a portion of the subsurface treatment area such that fracturing of the formation is inhibited.

955. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of barrier freeze wells in the formation;

injecting water in one or more barrier freeze wells to form a portion of the barrier around the subsurface treatment area;

adjusting the pressure in the treatment area such that the pressure in the treatment area substantially equilibrates with the pressure out of the treatment area; and

injecting water in one or more barrier freeze wells to form the barrier around the subsurface treatment area.

956. A method of establishing a barrier around at least a portion of a subsurface treatment area in a hydrocarbon containing formation, comprising:

forming a plurality of barrier freeze wells in the formation;

injecting water in one or more barrier freeze wells to form a portion of the barrier around the subsurface treatment area;

measuring a voltage difference between an interior and an exterior of one or more barrier; and

assessing an integrity of at the portion of the barrier using the measured voltage difference.

957. A method of forming a barrier in a formation, comprising:

heating a portion of a formation adjacent to a plurality of wellbores to raise a temperature of the formation adjacent to the wellbores above a mobilization temperature of bitumen and below a pyrolysis temperature of hydrocarbons in the formation; and

allowing the bitumen to move outwards from the wellbores towards a portion of the formation comprising water cooler than the mobilization temperature of the bitumen so that the bitumen solidifies in the formation to form a barrier.

958. The method of claim 957, wherein the barrier comprises bitumen and water.

959. The method of claim 957, wherein at least one heater used to heat the portion of the formation adjacent the wellbores comprises a temperature limited heater.

960. The method of claim 957, wherein a portion of the formation comprising water is substantially above the portion of a formation adjacent to a plurality of wellbores.

961. The method of claim 957, further comprising contacting the bitumen with the cool water in the formation to form the barrier.

962. The method of claim 957, further comprising using an in situ heat treatment process on a treatment area inside the barrier.

963. The method of claim 957, further comprising storing carbon dioxide inside the barrier.

964. The method of claim 957, further comprising forming the barrier between an existing barrier and a treatment area used to produce formation fluid from the formation.

965. The method of claim 957, wherein a temperature of the formation adjacent to the wellbores ranges from about 80 °C to about 150 °C.

966. The method of claim 957, further comprising inhibiting production of hydrocarbon gases from the heated portion.

967. A method of forming a barrier in a formation, comprising:

assessing an amount of water in a first portion of a formation;

providing a selected number of heater wellbores based on the amount of water in the first portion of the formation to a second portion of the formation;

heating the second portion of a formation with the selected number of heater wellbores to raise a temperature of the formation adjacent to the wellbores above a mobilization temperature of bitumen and below a pyrolysis temperature of hydrocarbons in the formation; and

allowing the bitumen to move outwards from the wellbores towards the first portion of the formation, wherein the water in the first portion is cooler than the mobilization temperature of the bitumen so that the bitumen solidifies in the formation to form a barrier between the first portion and the second portion.

968. The method of claim 967, wherein the selected number of heater wellbores is one.

969. The method of claim 967, wherein the selected number of heater wellbores are at least 20 m from an edge of an area treated by an in situ heat treatment process.

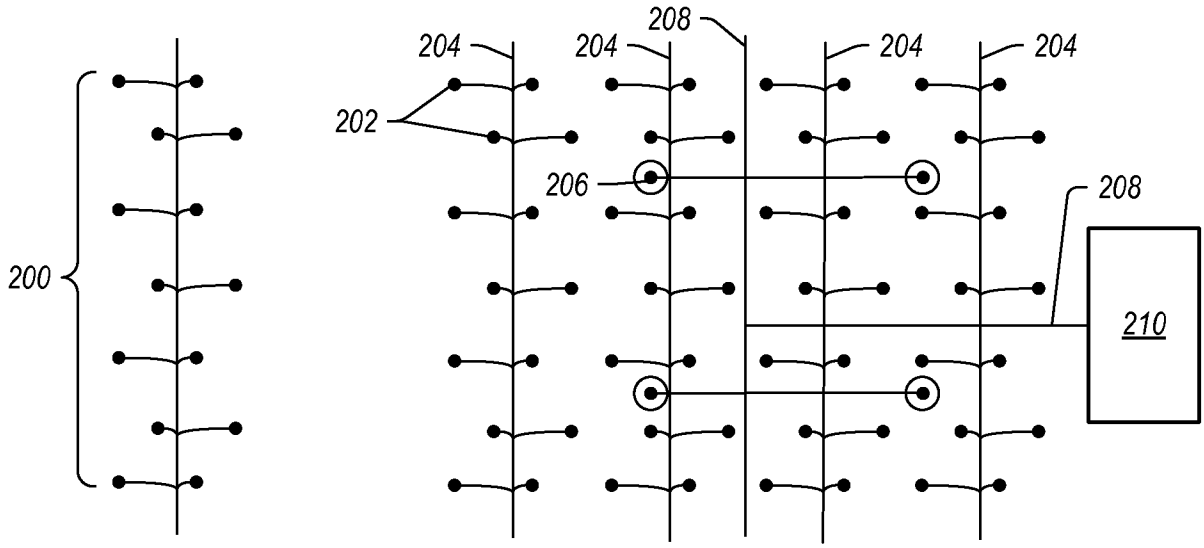

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FIG. 1

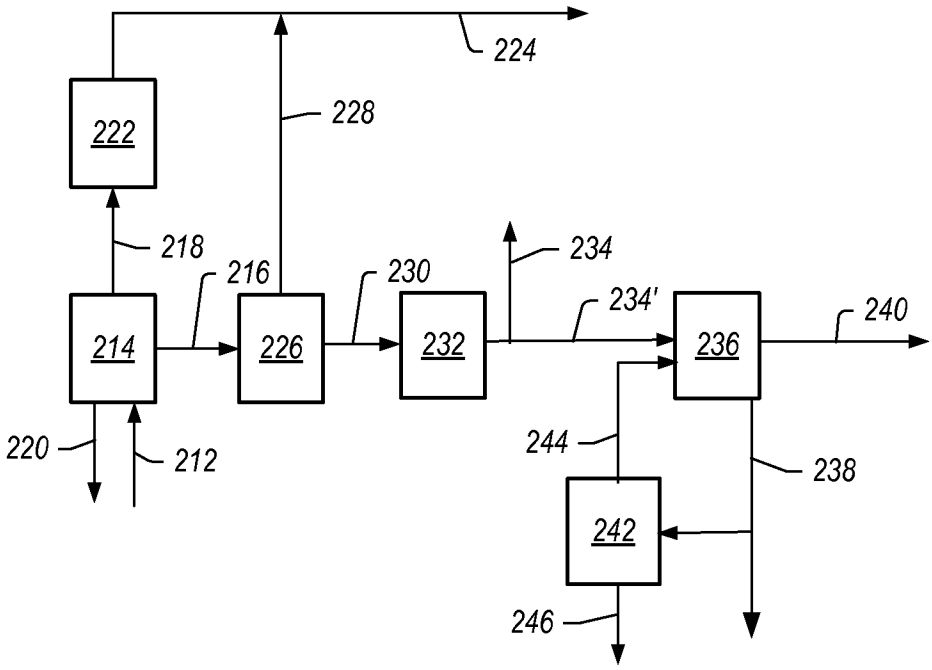

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FIG. 2

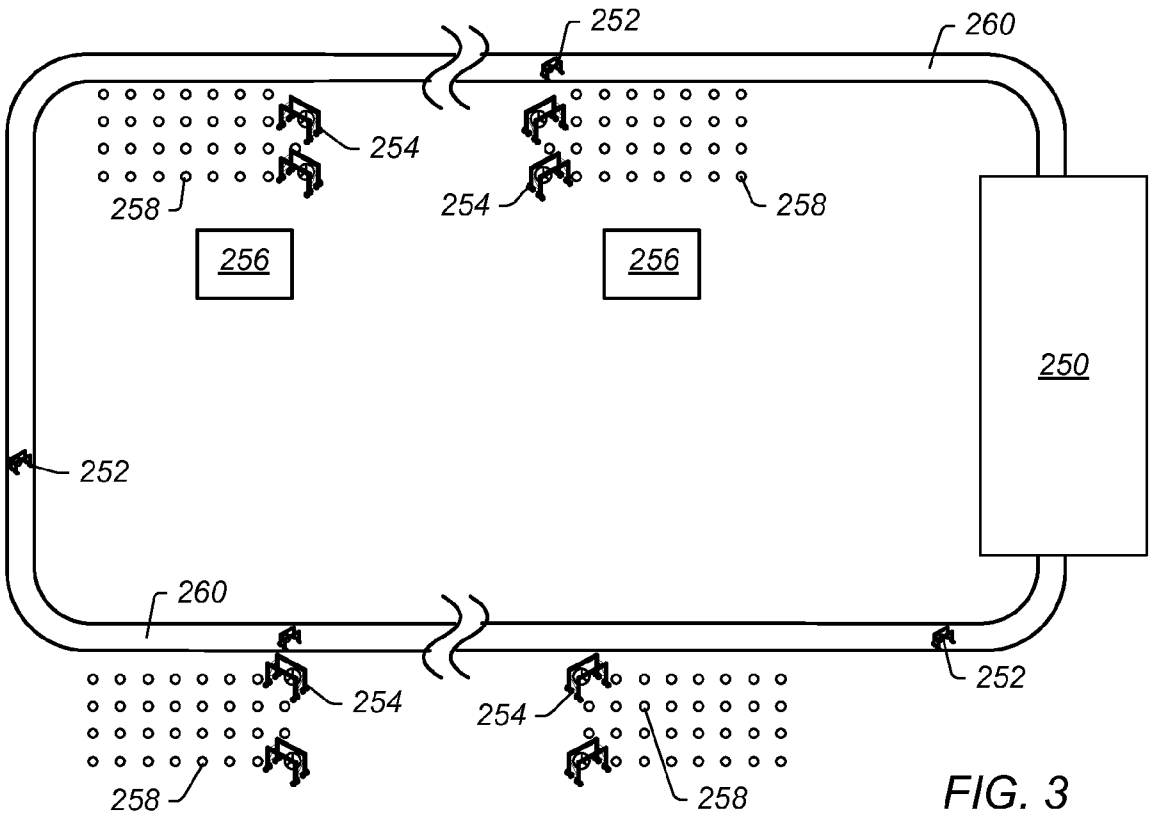

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FIG. 3

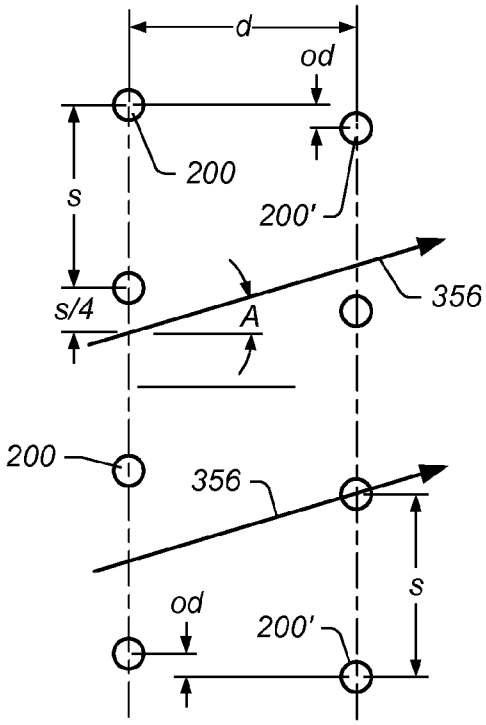

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FIG. 4

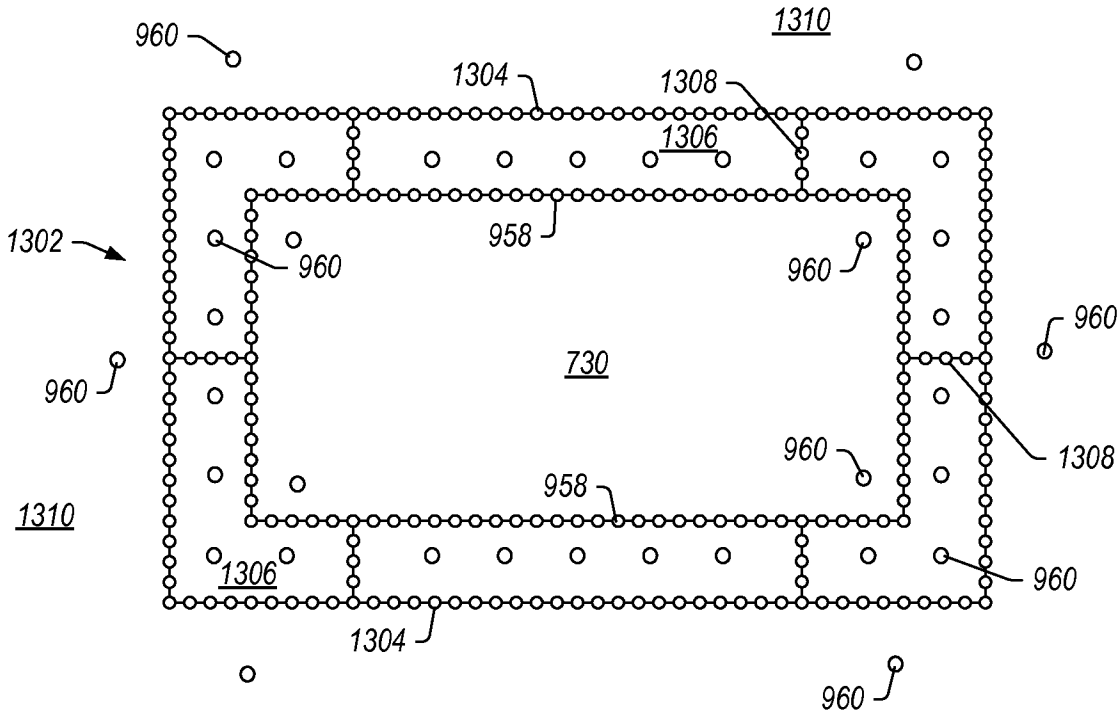

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FIG. 5

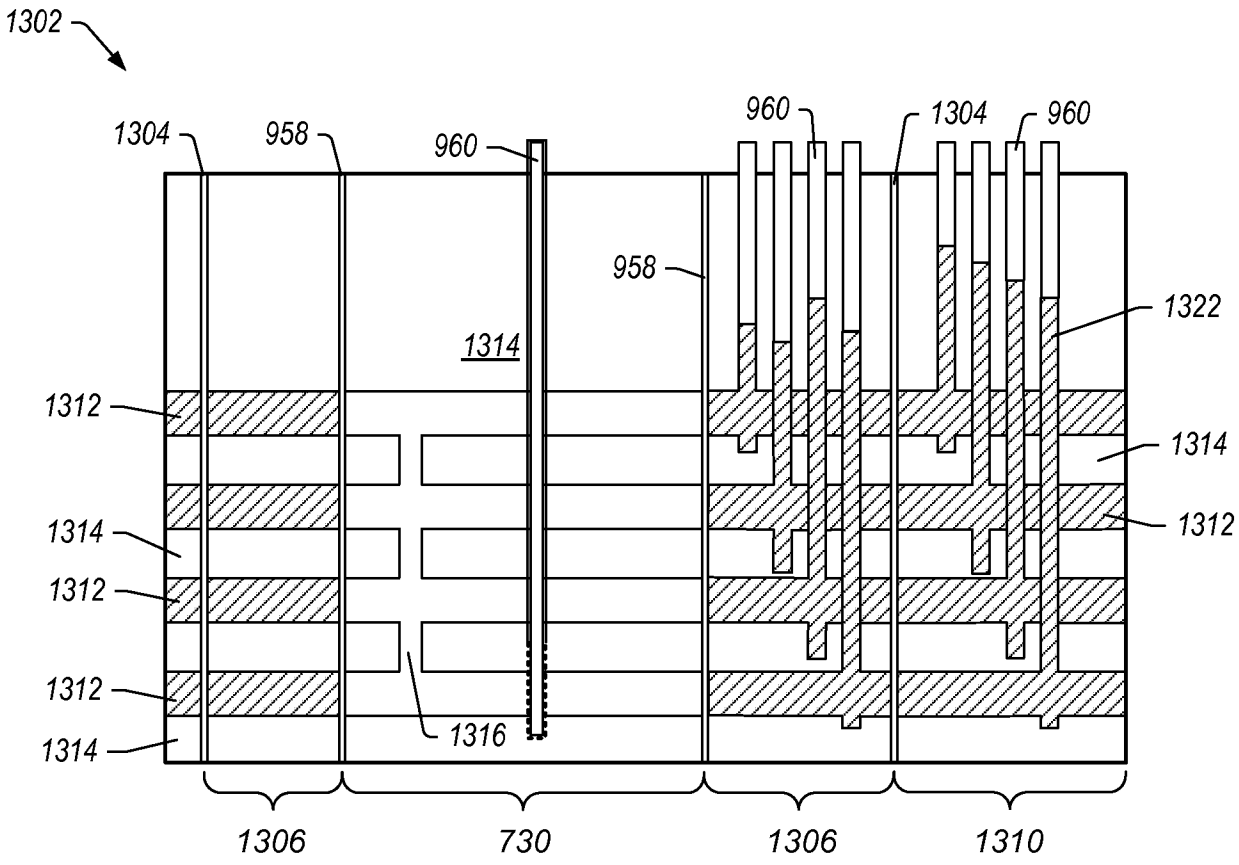

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FIG. 7

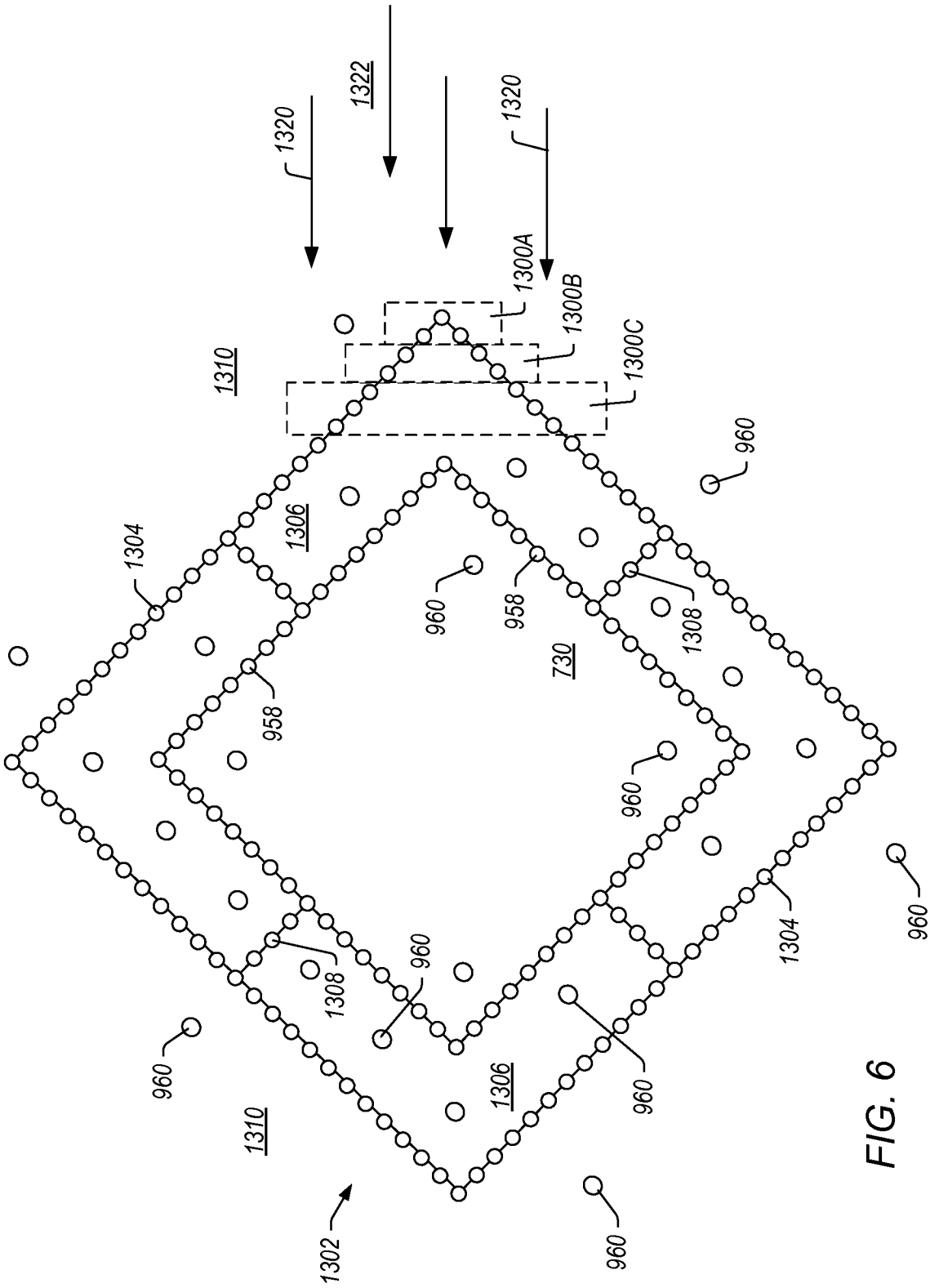

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FIG. 6

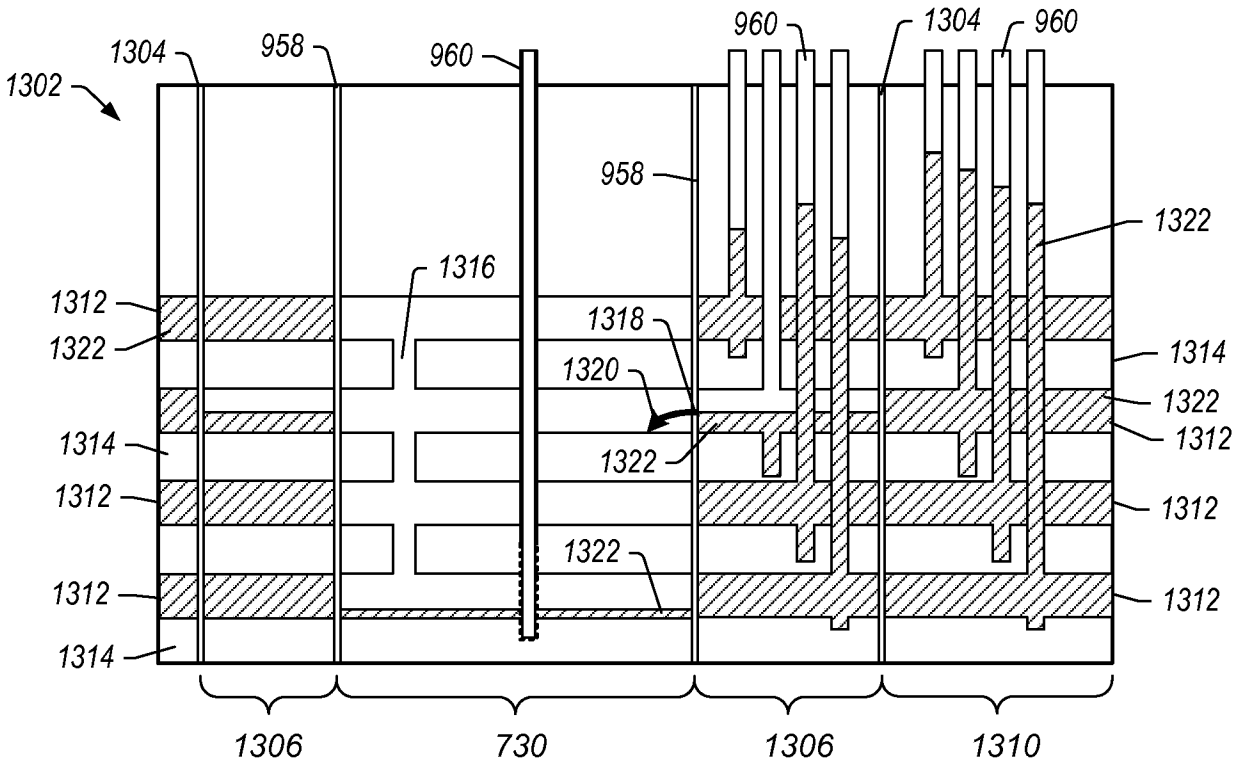

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FIG. 8

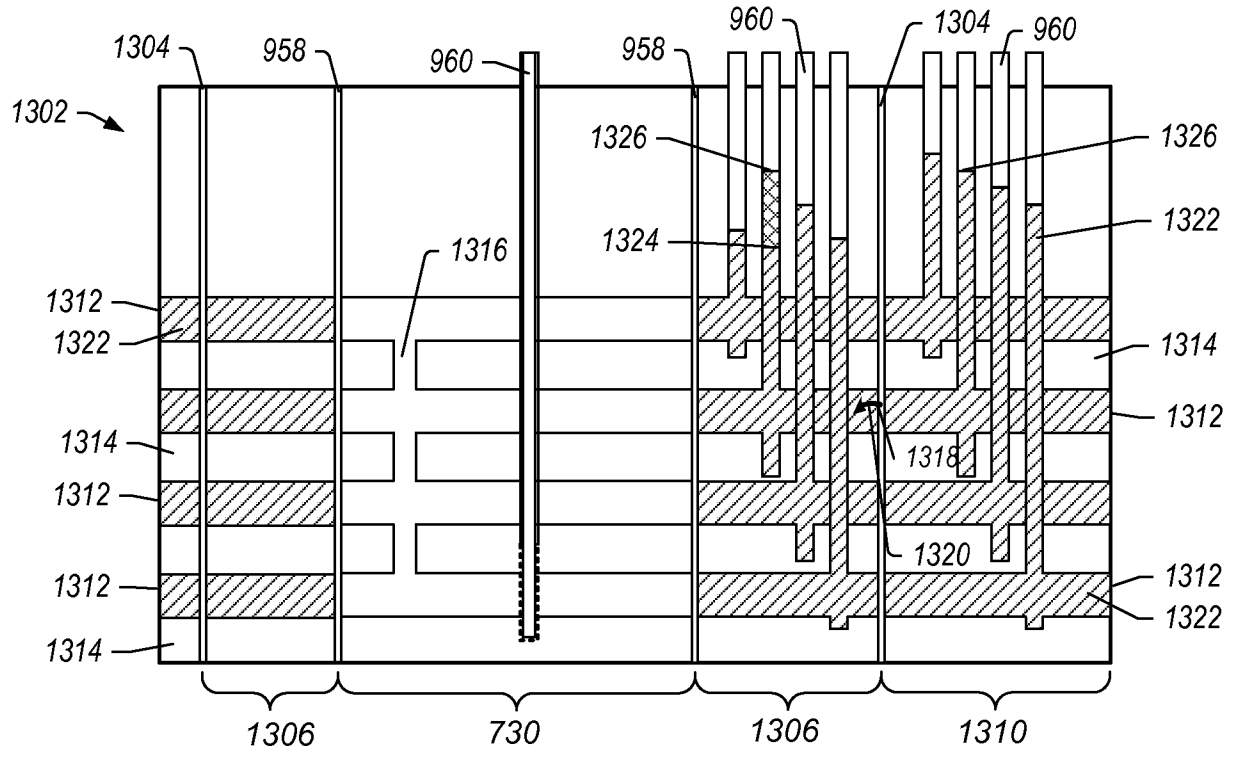

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FIG. 9

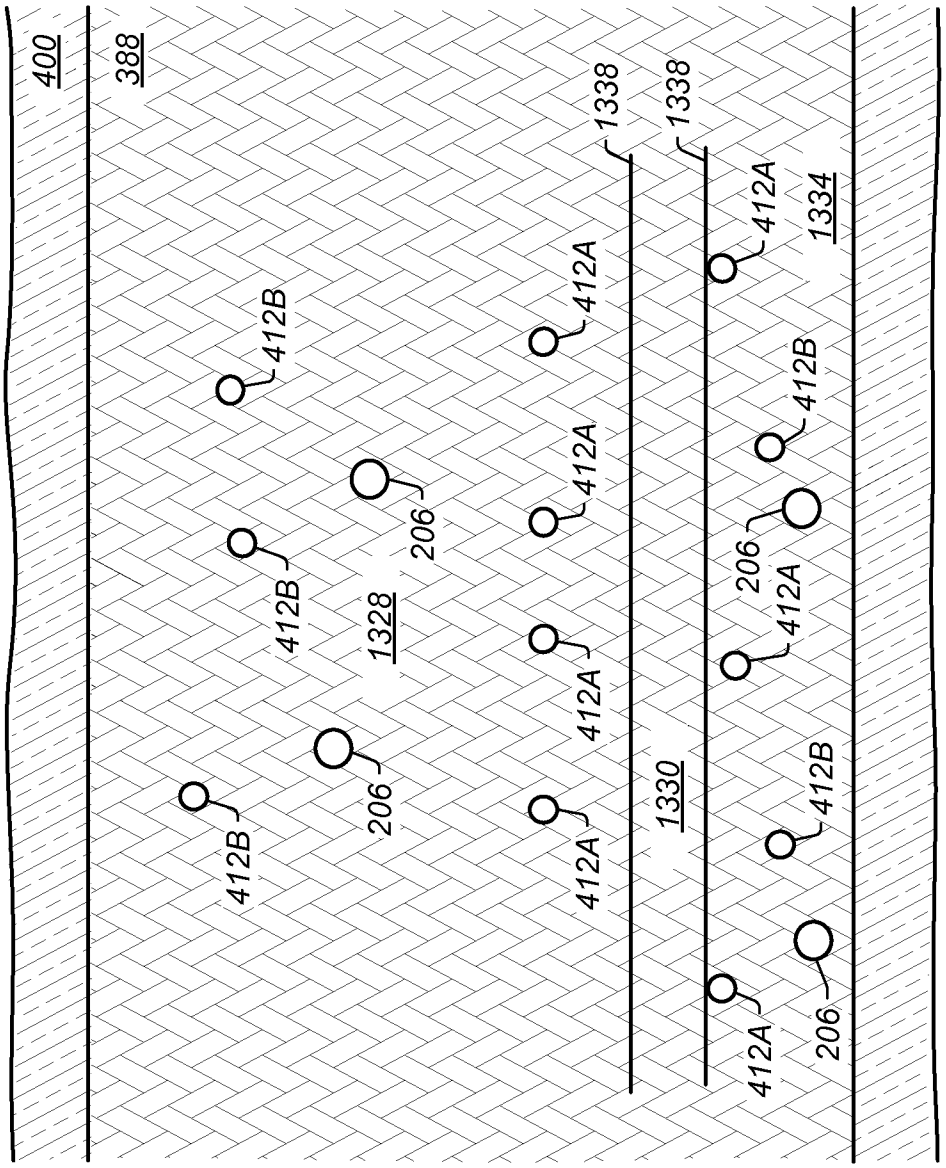
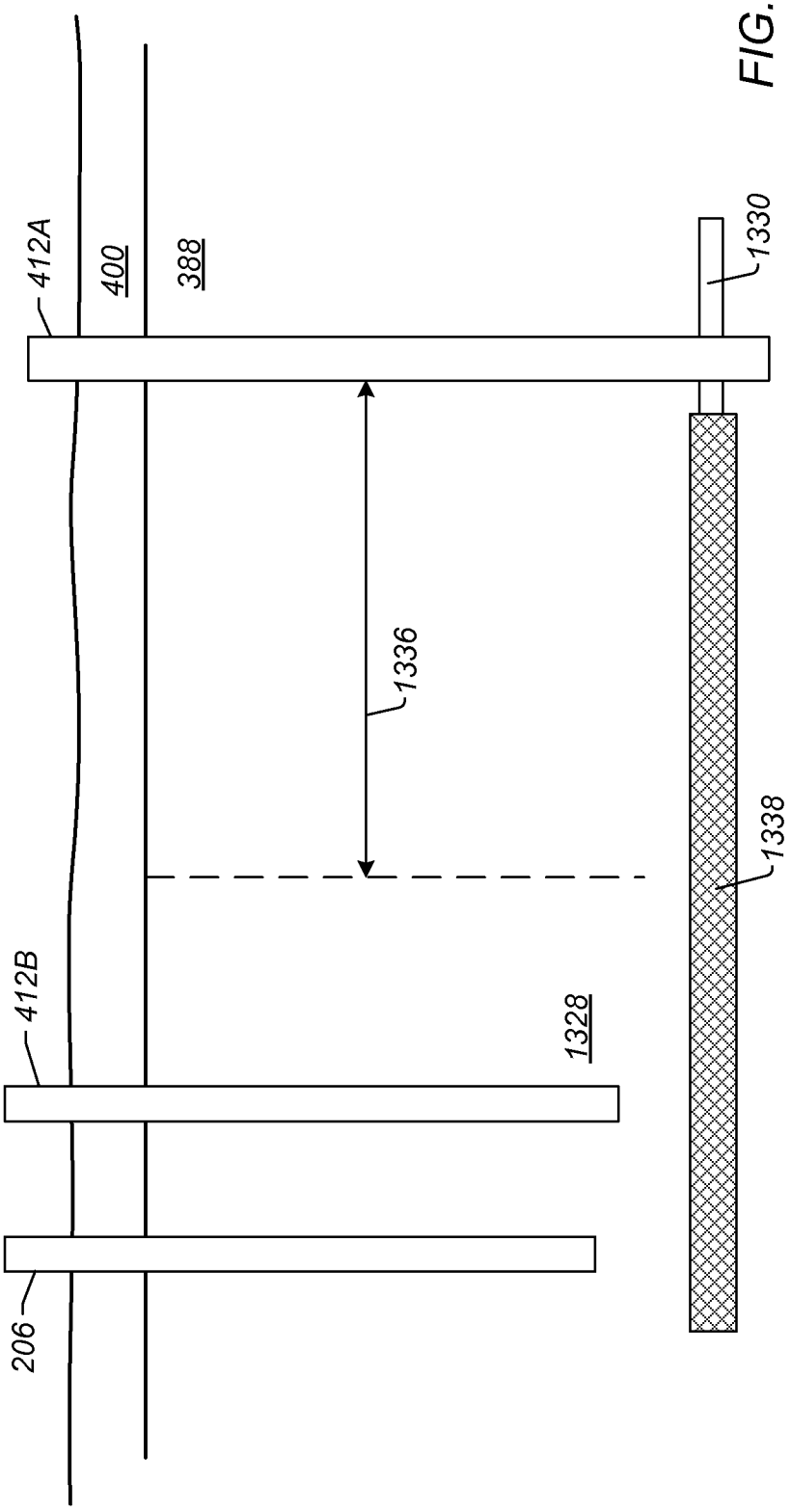

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FIG. 10

FIG. 11



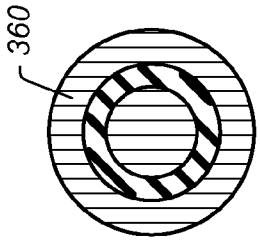


FIG. 14

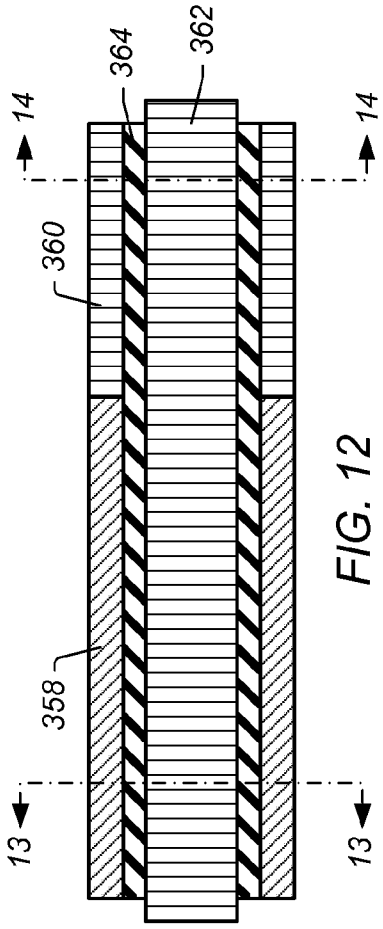


FIG. 12

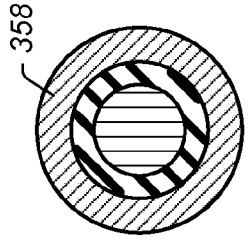


FIG. 13

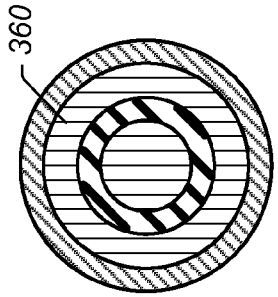


FIG. 17

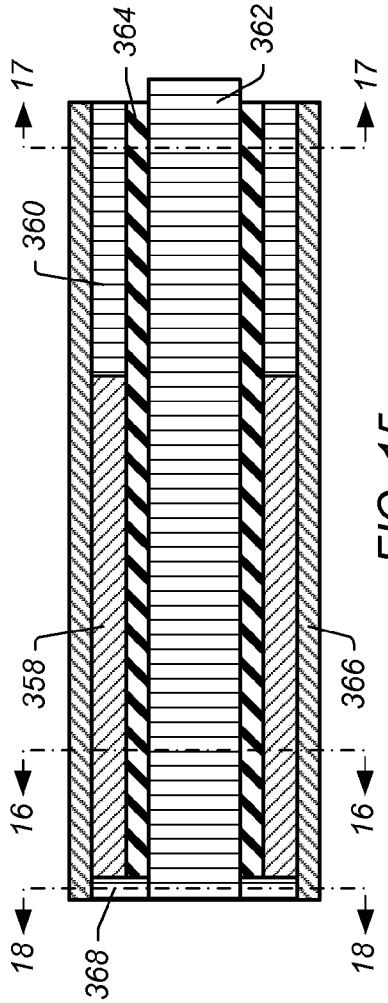


FIG. 15

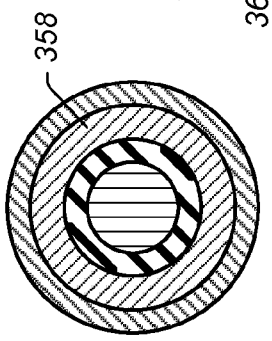


FIG. 16

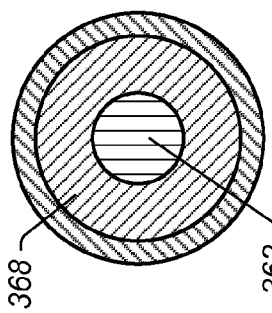


FIG. 18

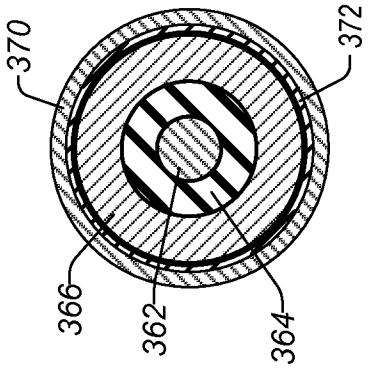


FIG. 19B

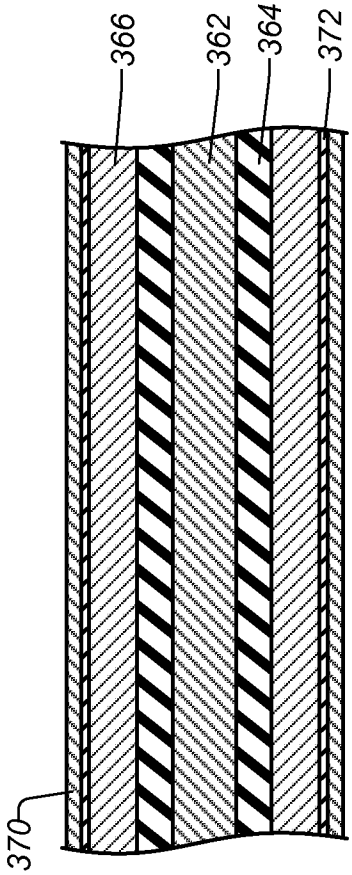


FIG. 19A

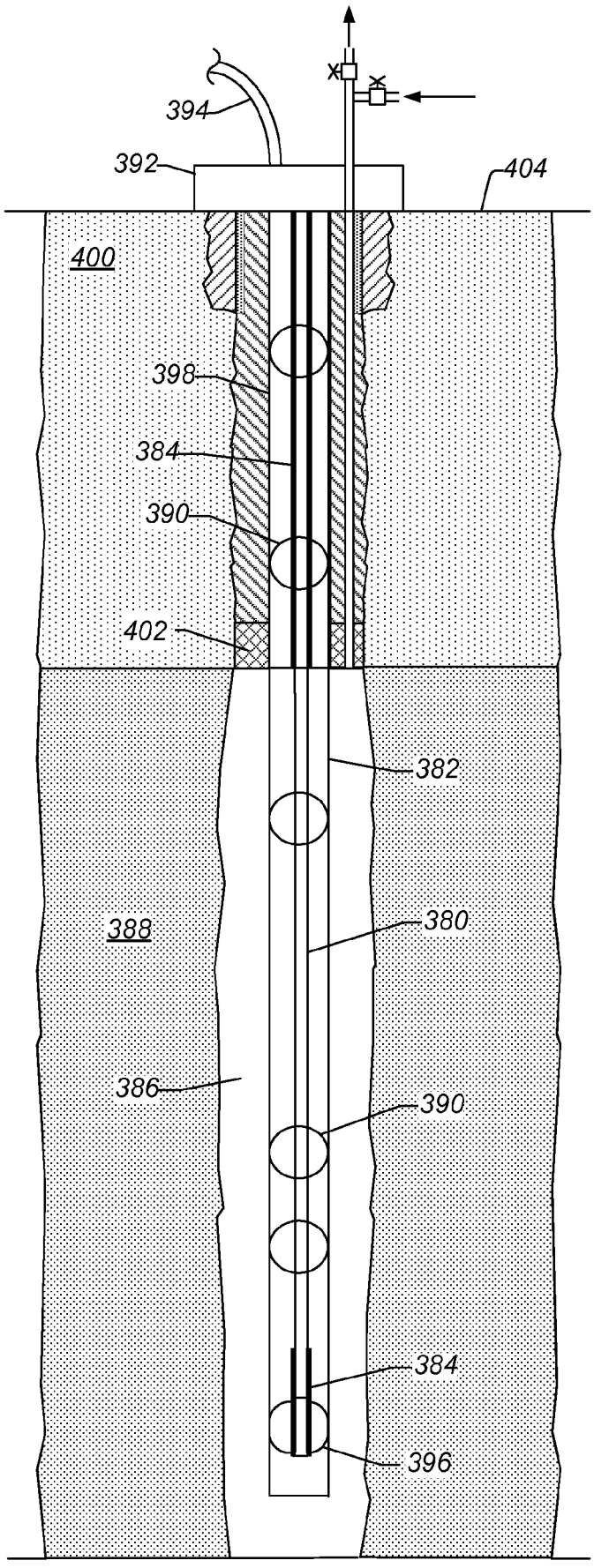


FIG. 24

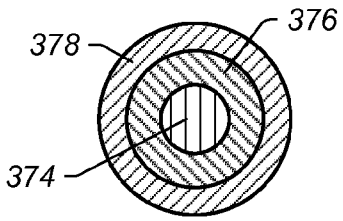


FIG. 20

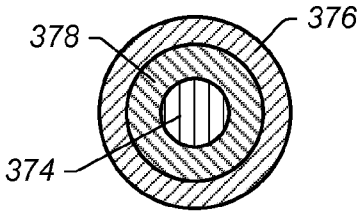


FIG. 21

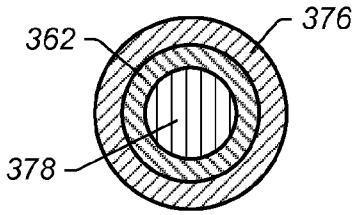


FIG. 22

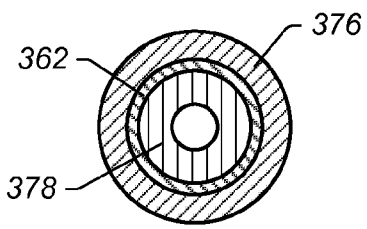


FIG. 23

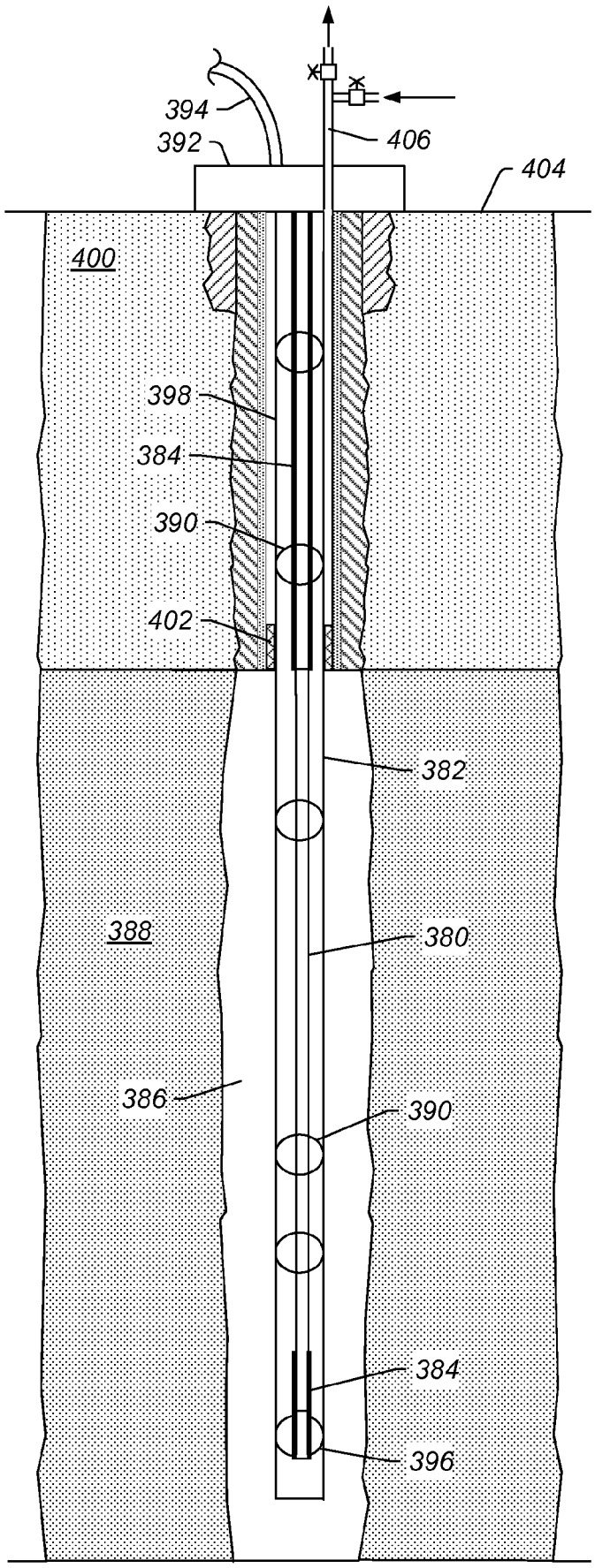


FIG. 25

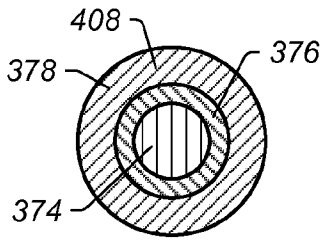


FIG. 26

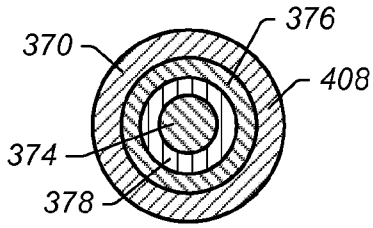


FIG. 27

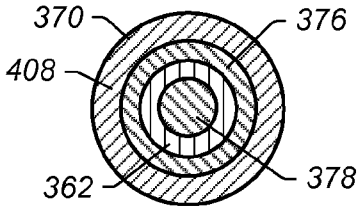


FIG. 28

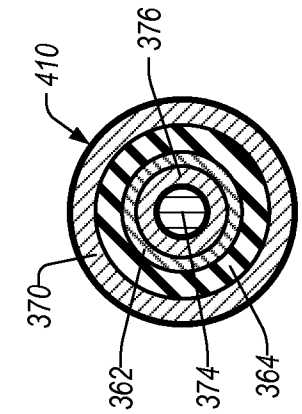


FIG. 29B

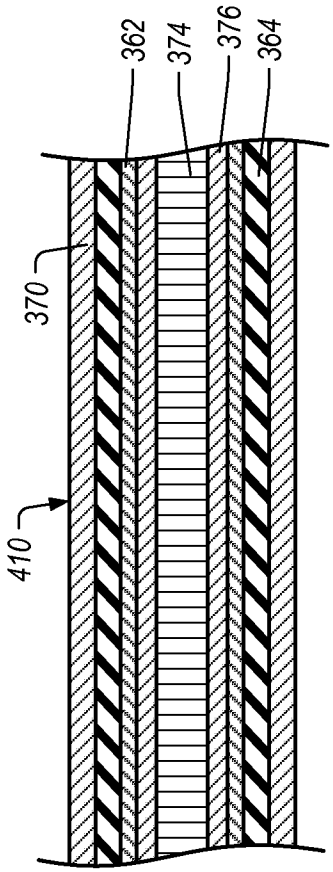


FIG. 29A

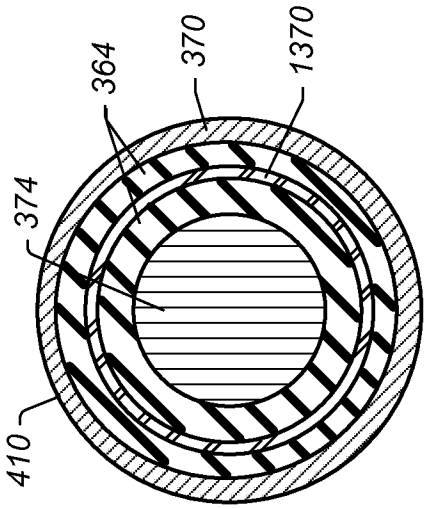


FIG. 31

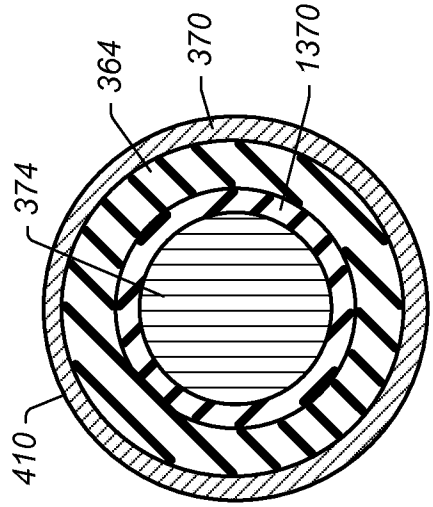


FIG. 30

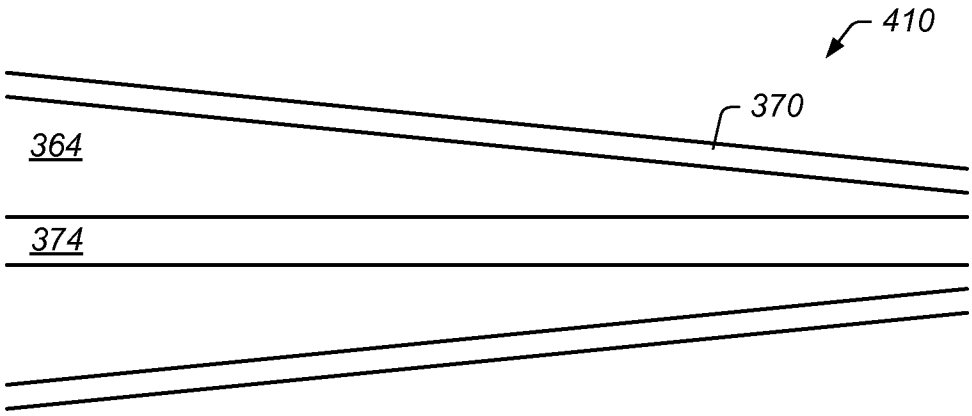


FIG. 32

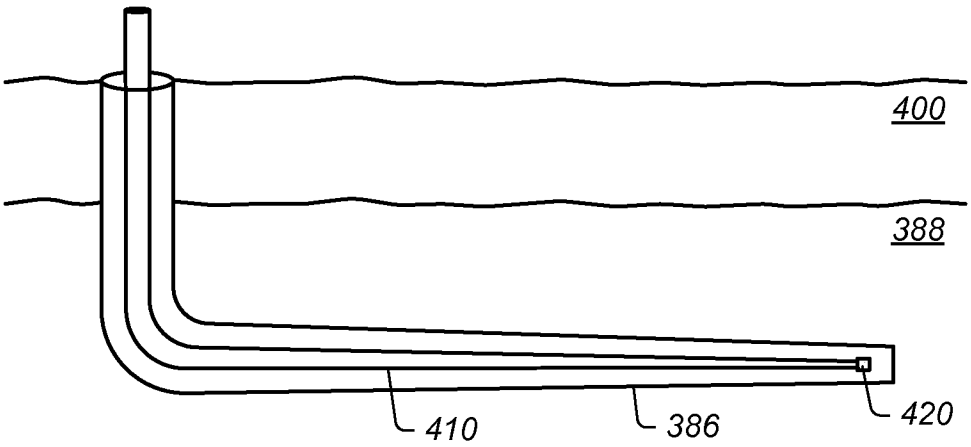


FIG. 33

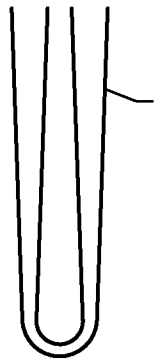


FIG. 34

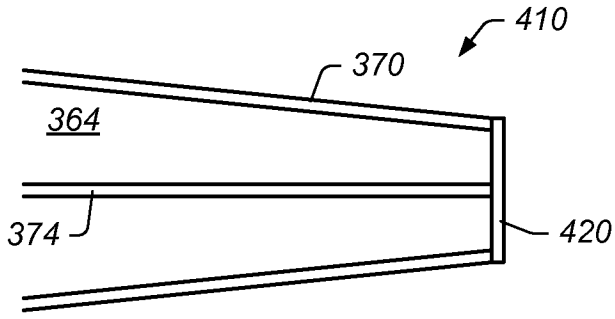


FIG. 35

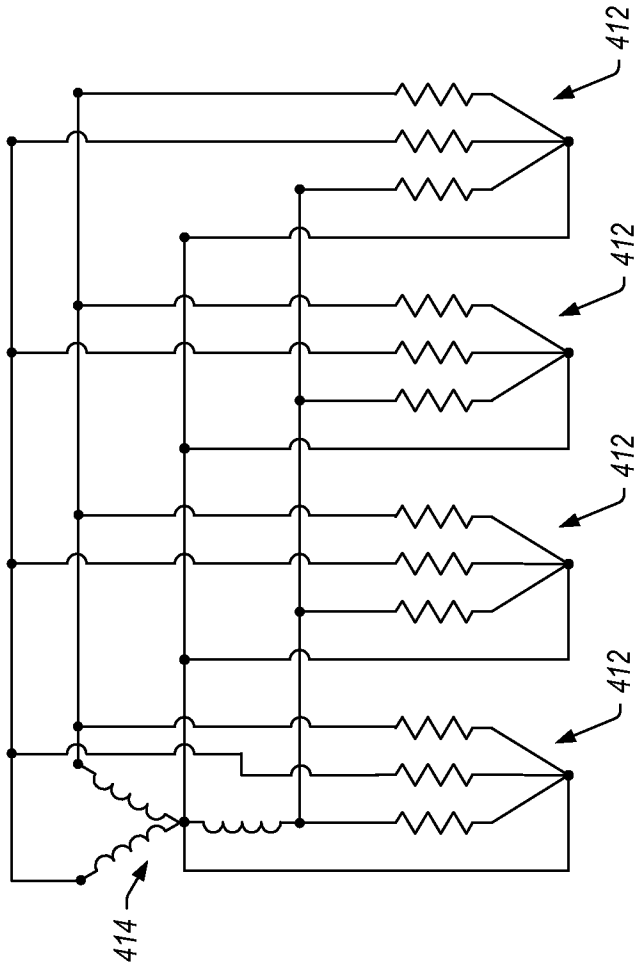


FIG. 37

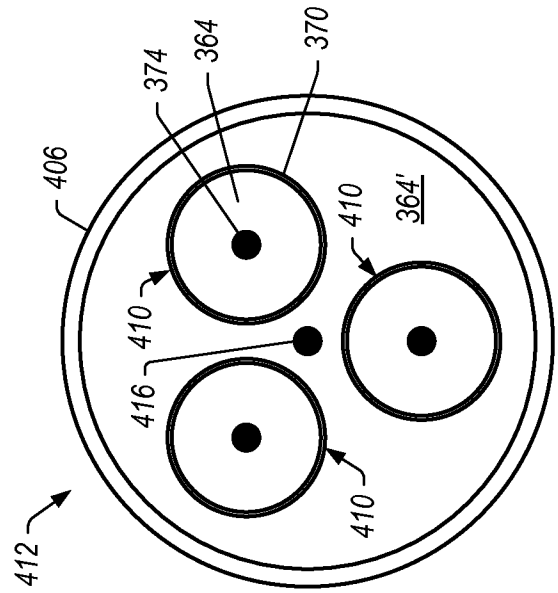


FIG. 36

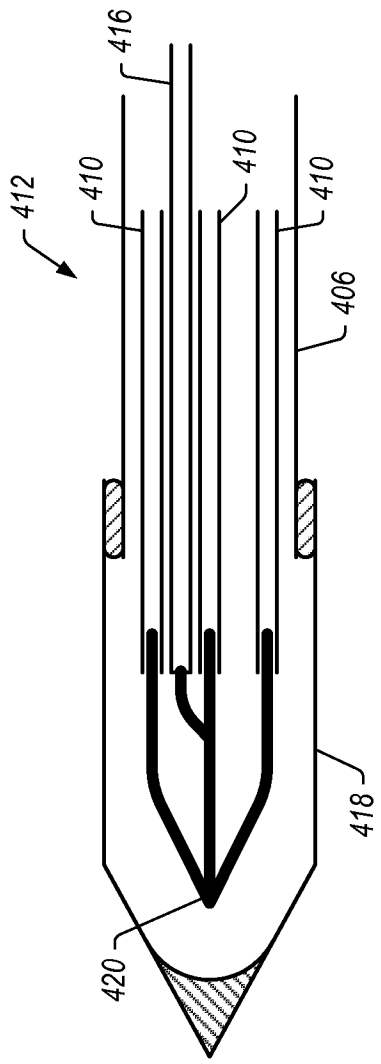


FIG. 38

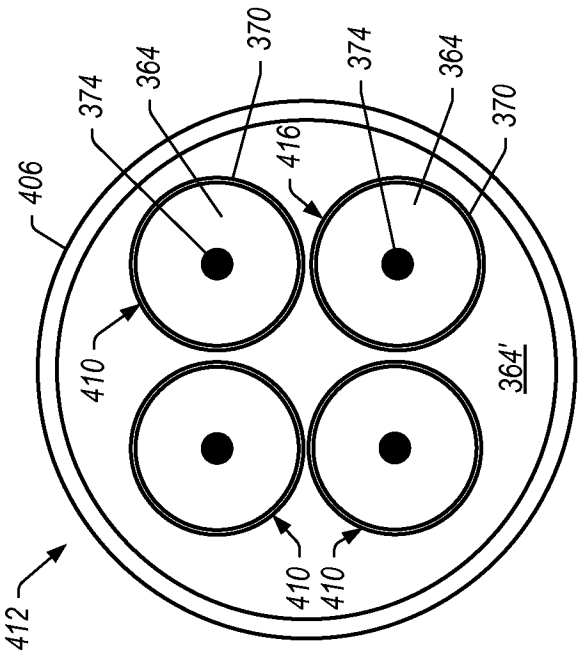


FIG. 40

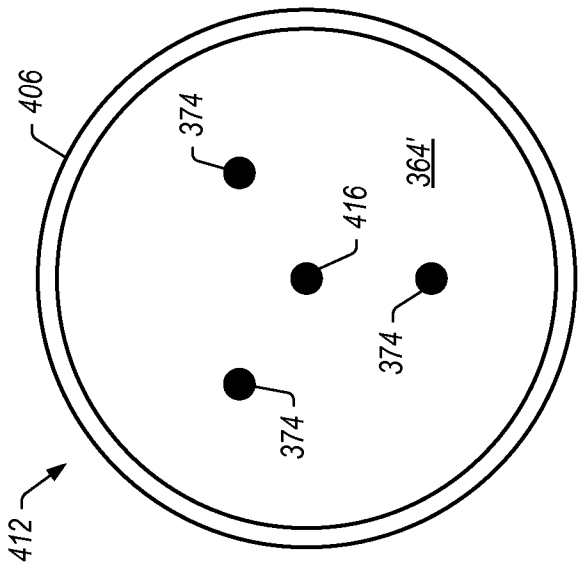


FIG. 39

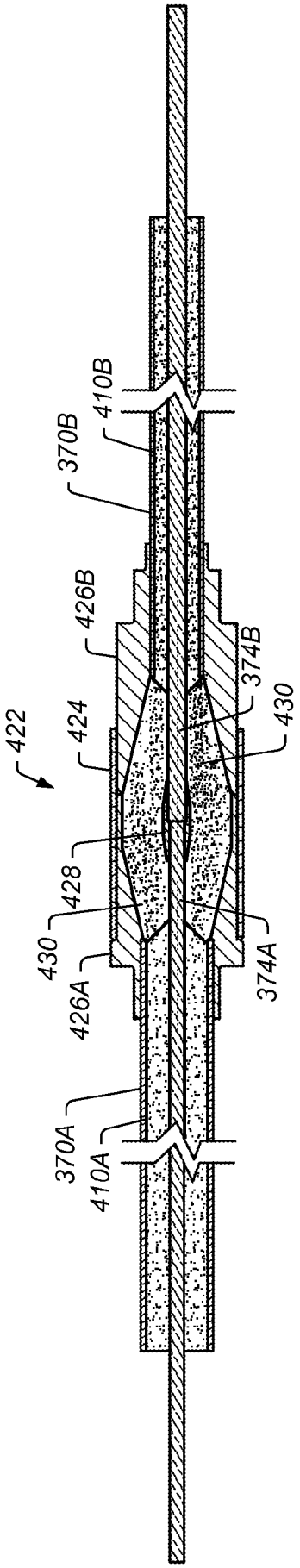


FIG. 41

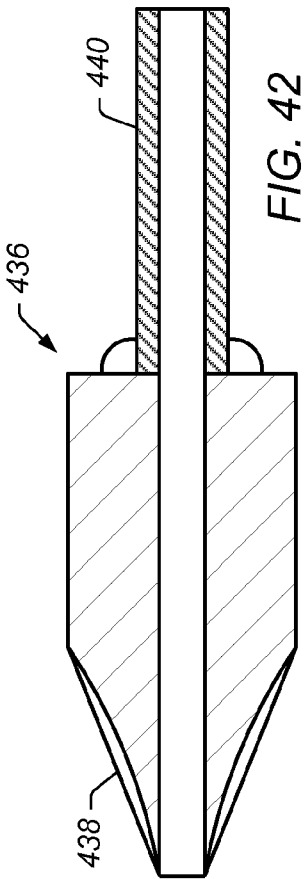


FIG. 42

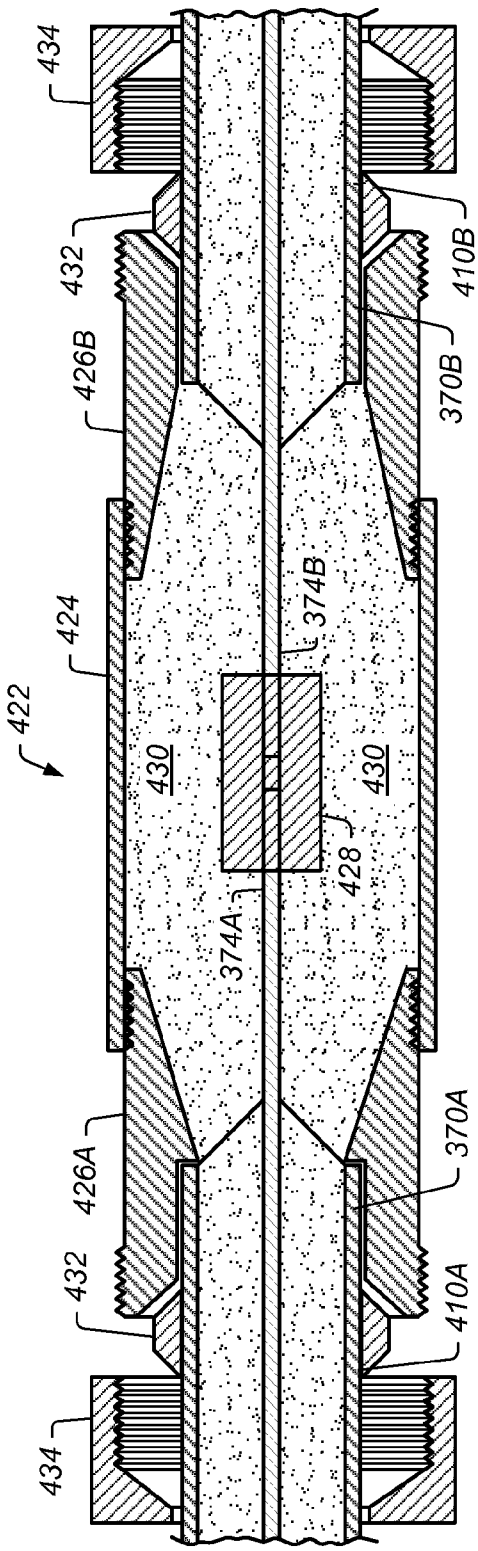


FIG. 43

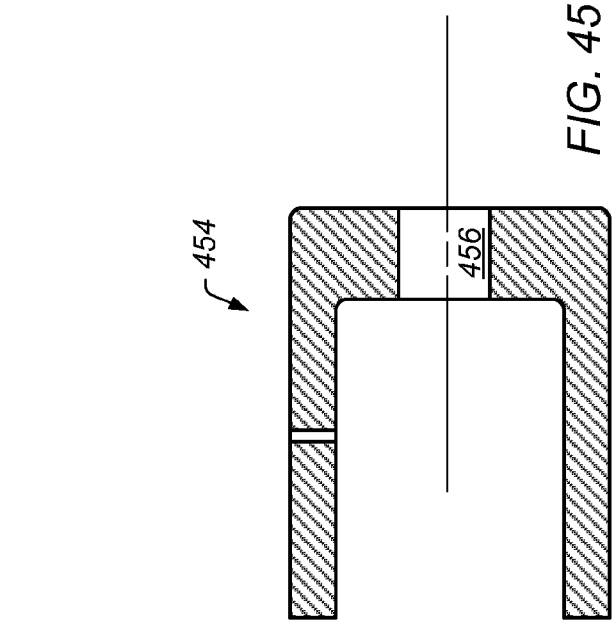


FIG. 45

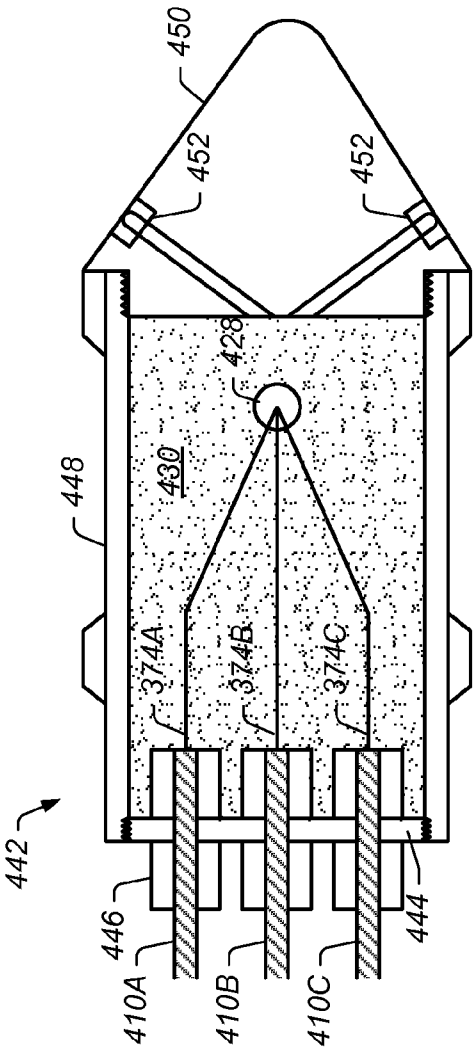


FIG. 44A

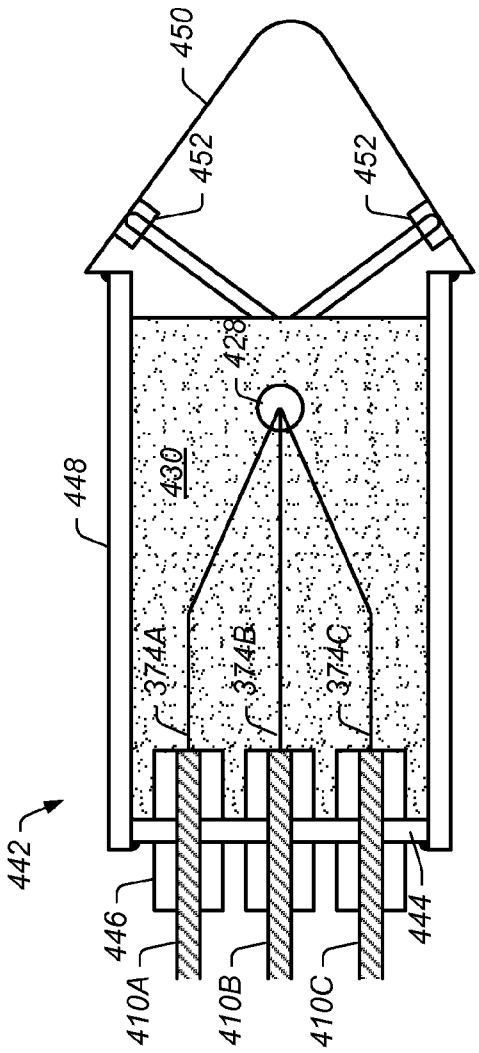


FIG. 44B

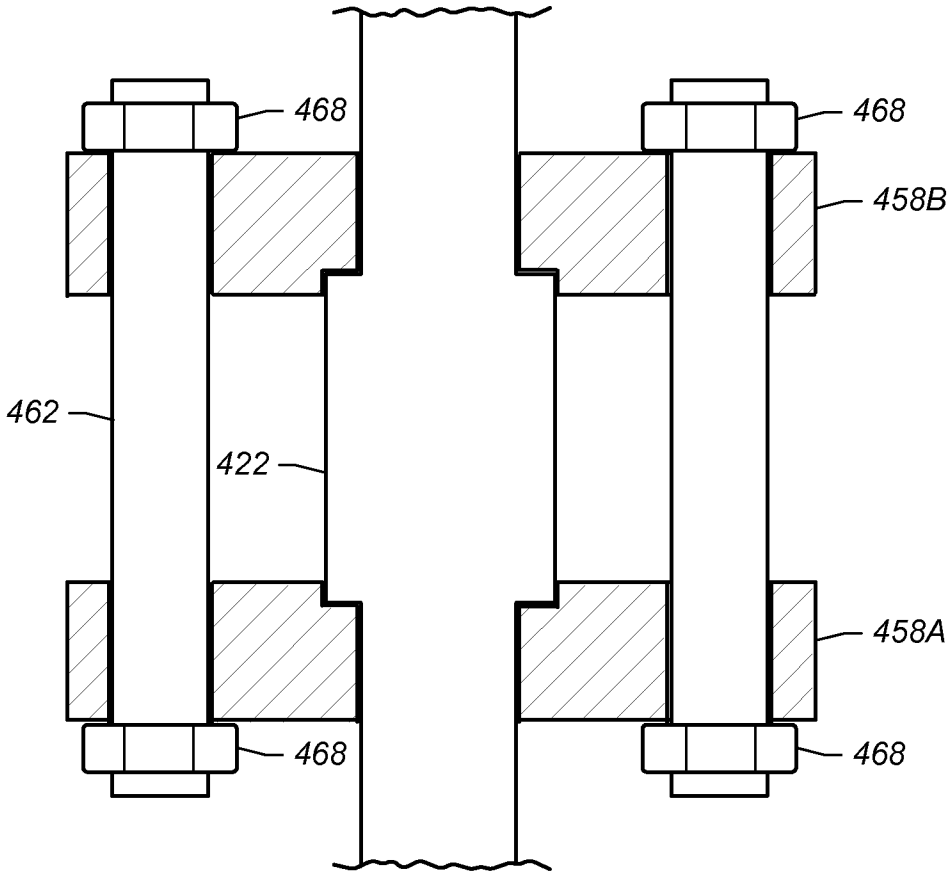


FIG. 46

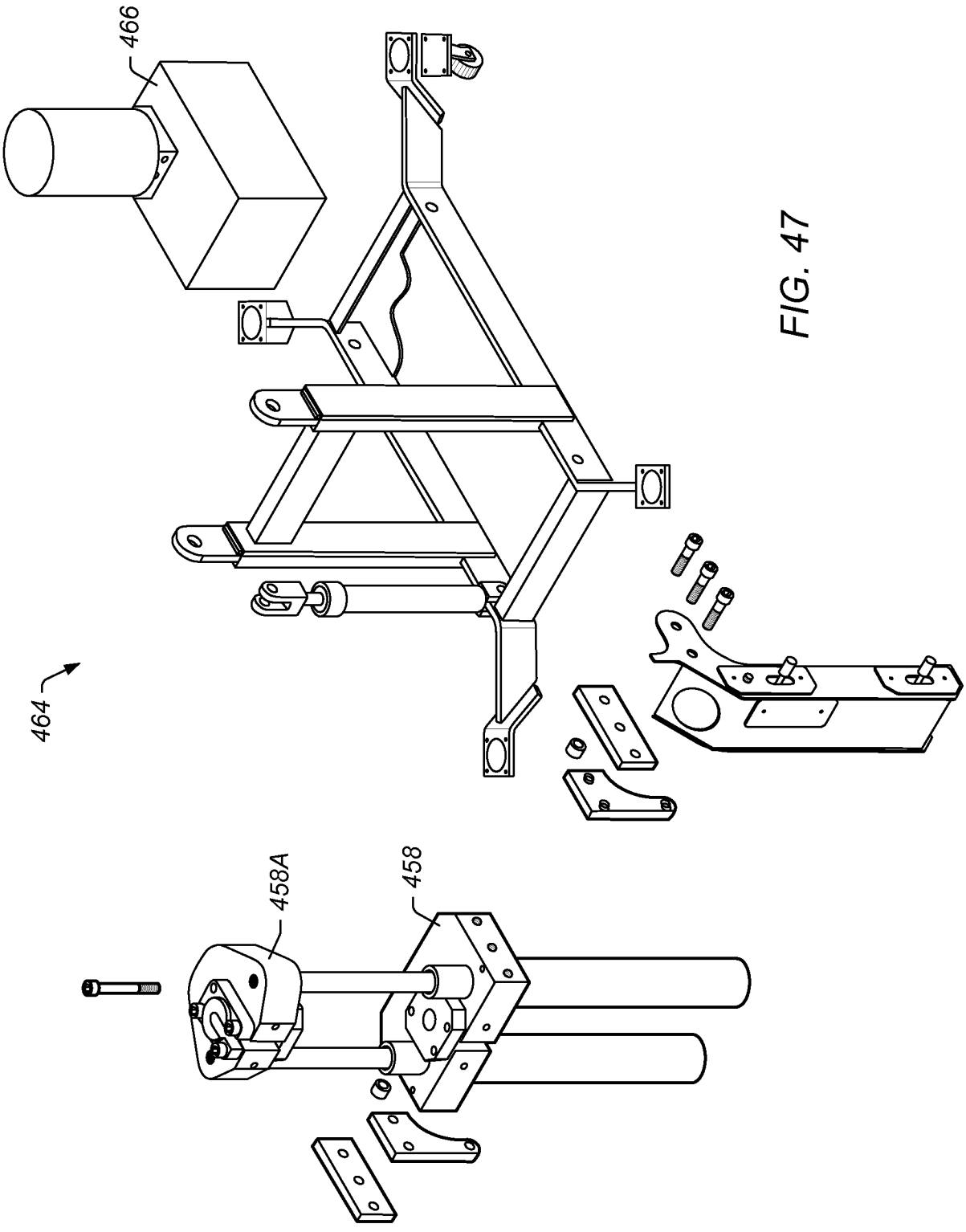


FIG. 47

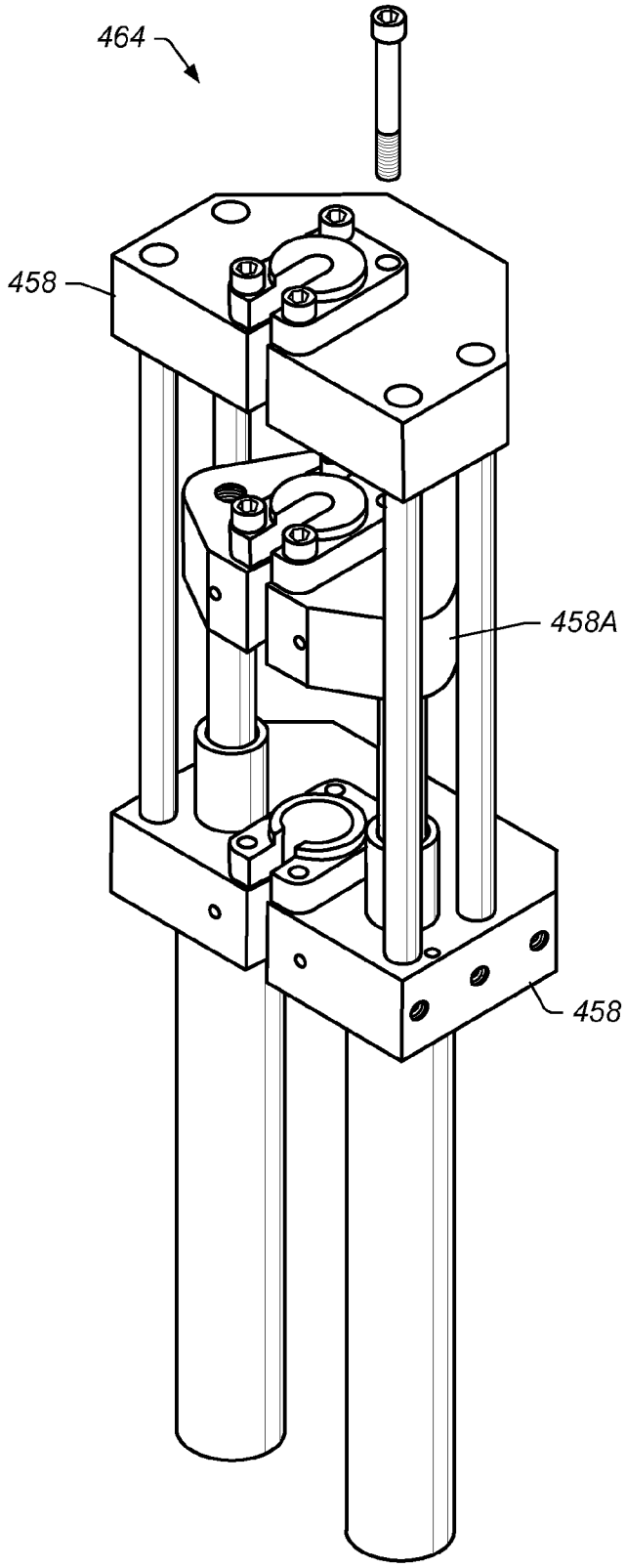


FIG. 48

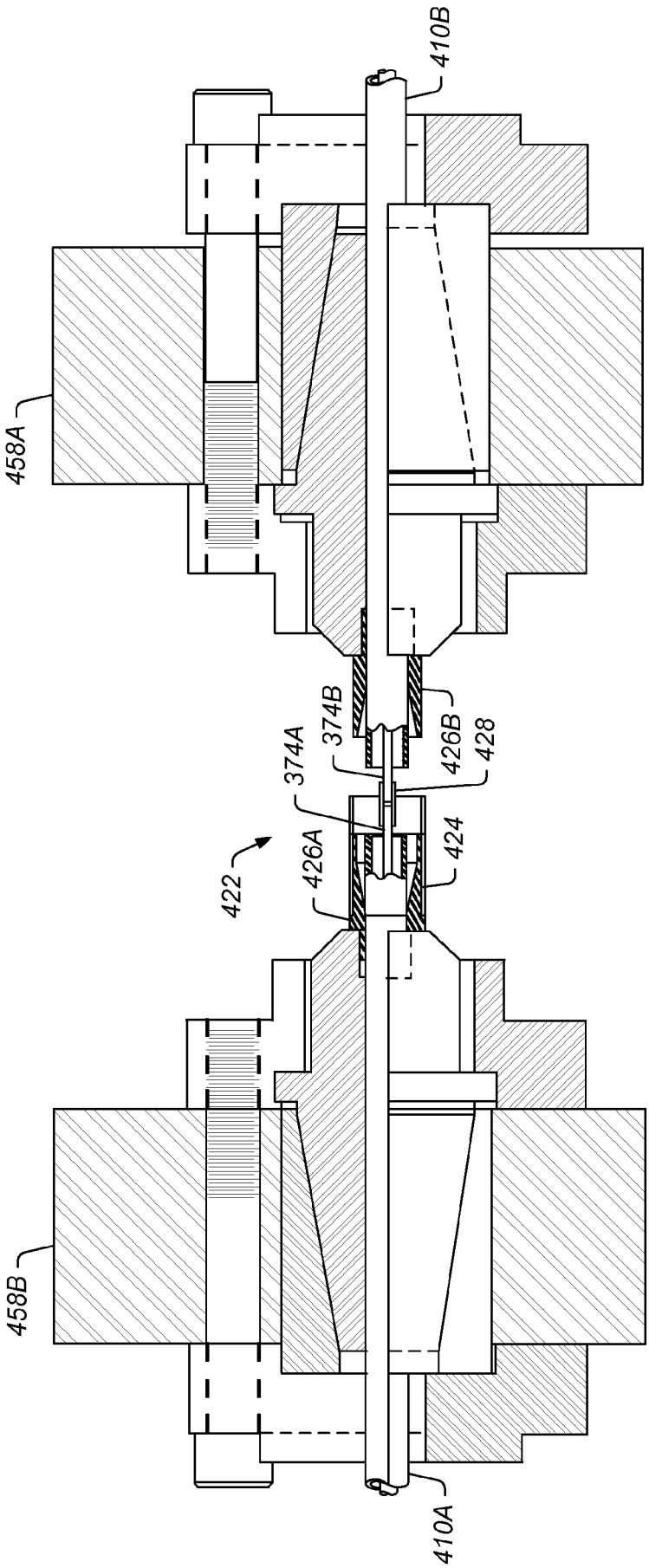


FIG. 49

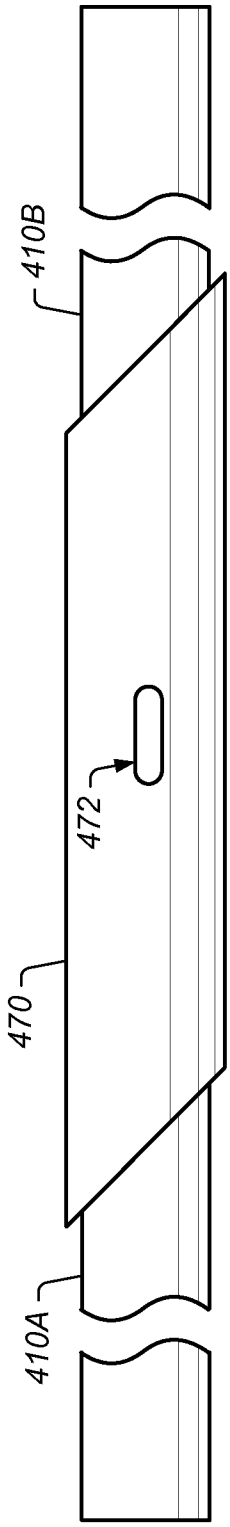


FIG. 50

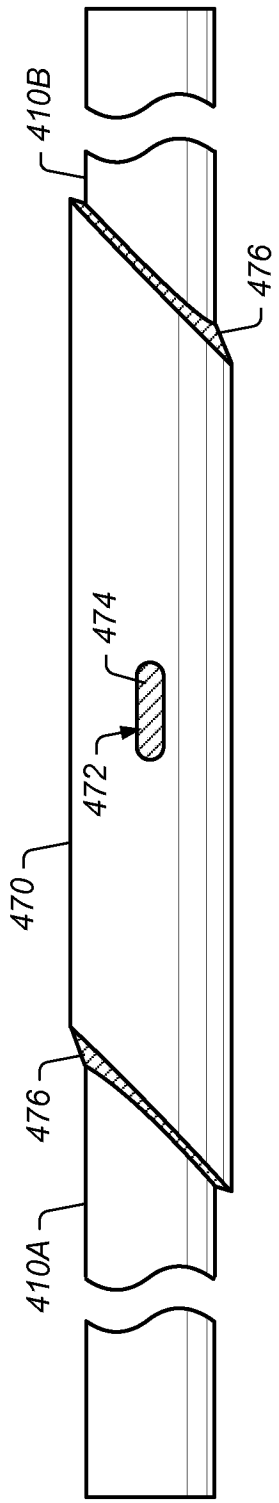


FIG. 51

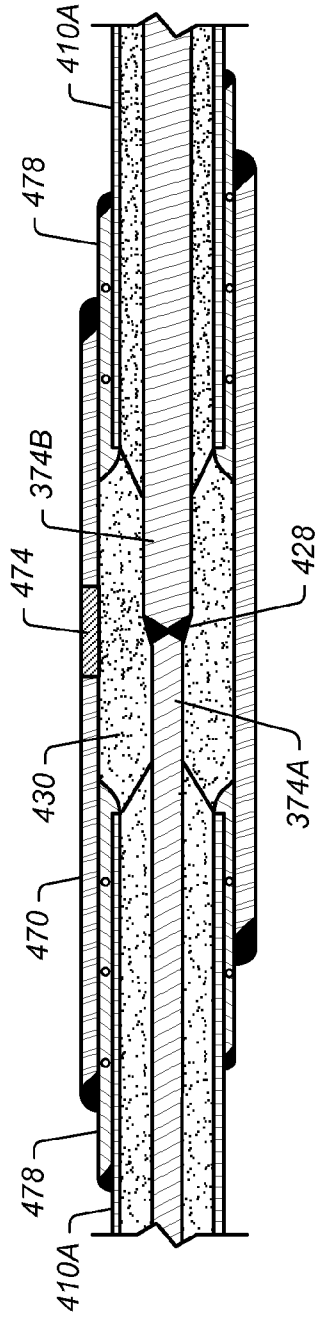


FIG. 52

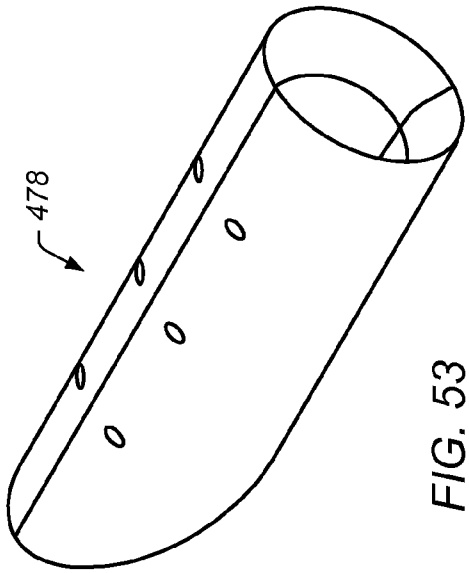


FIG. 53

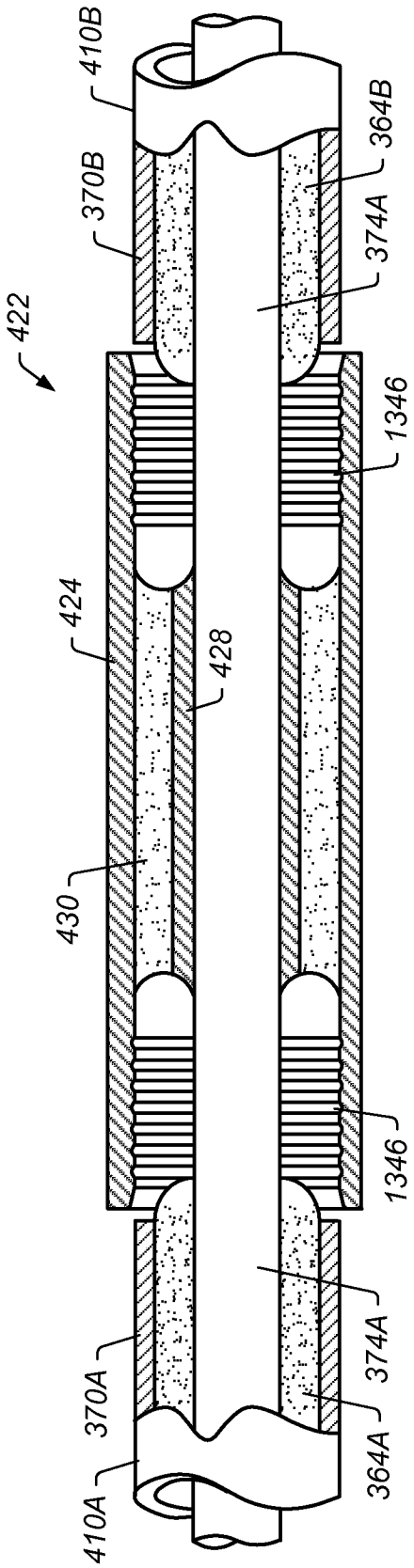

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FIG. 54

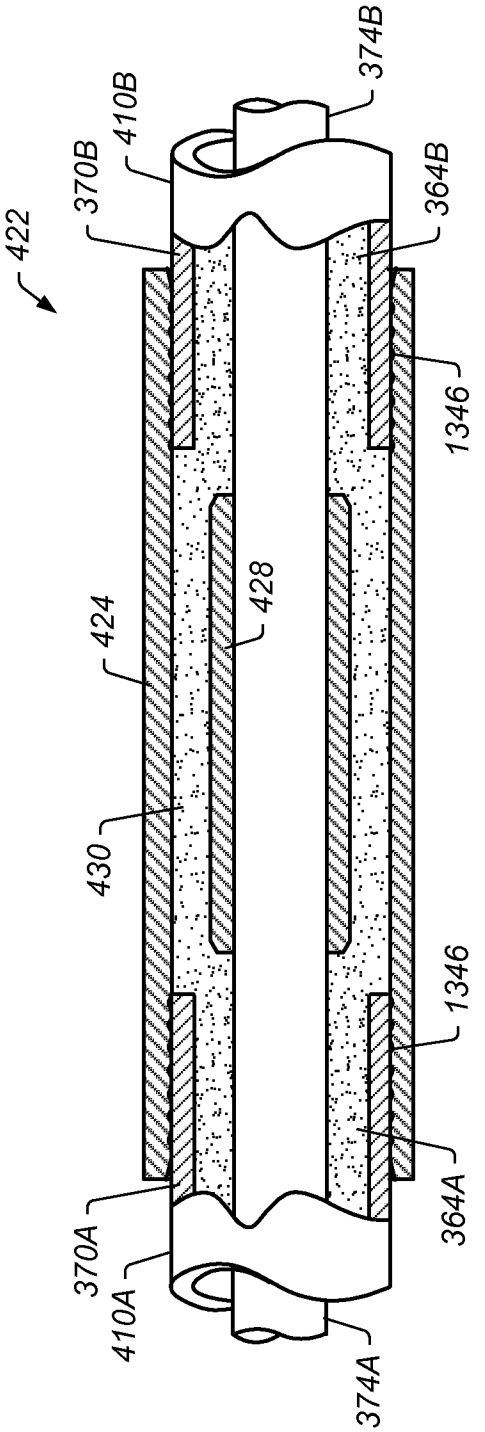

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FIG. 55

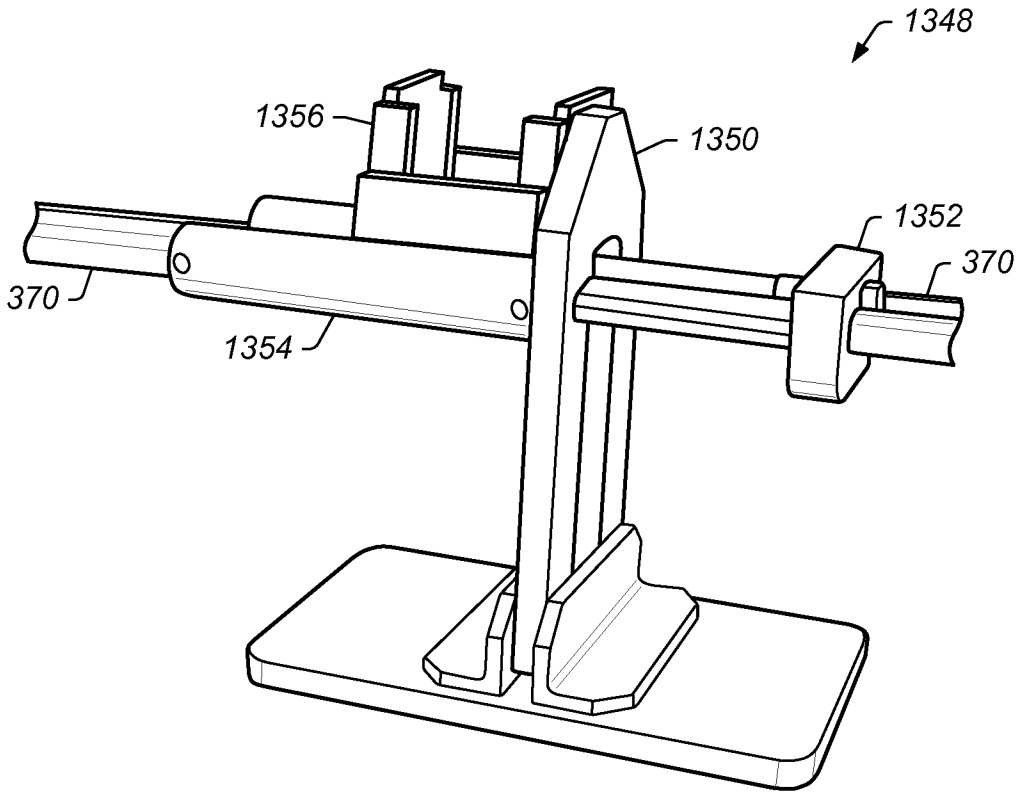

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FIG. 56

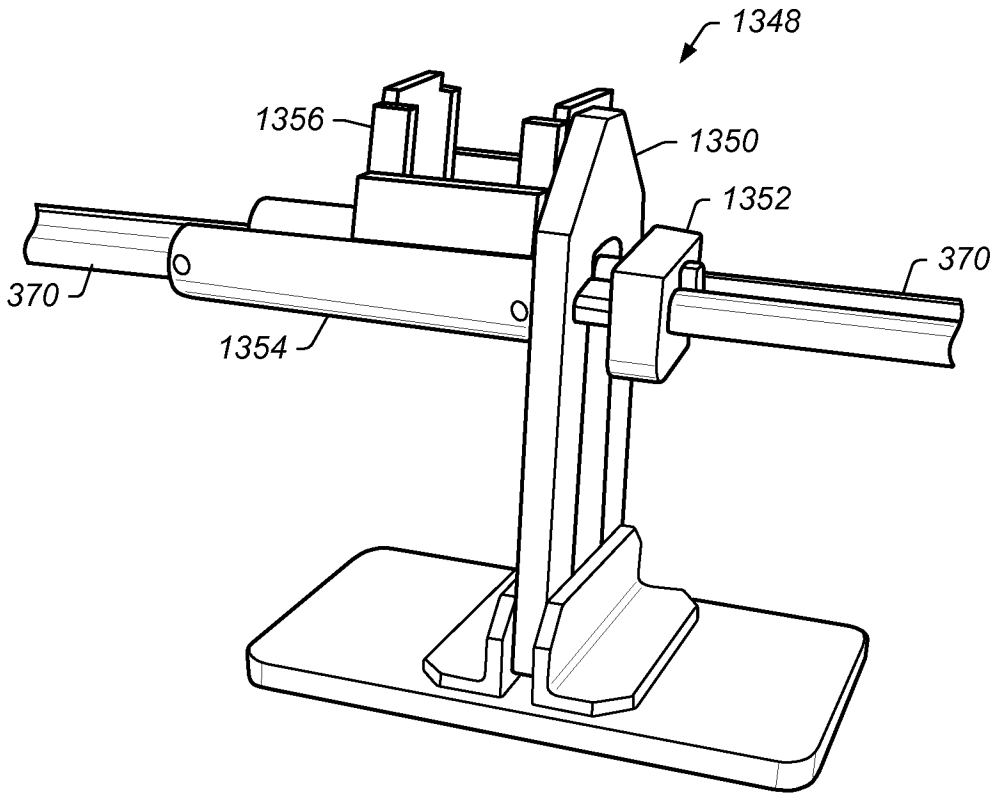

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FIG. 57

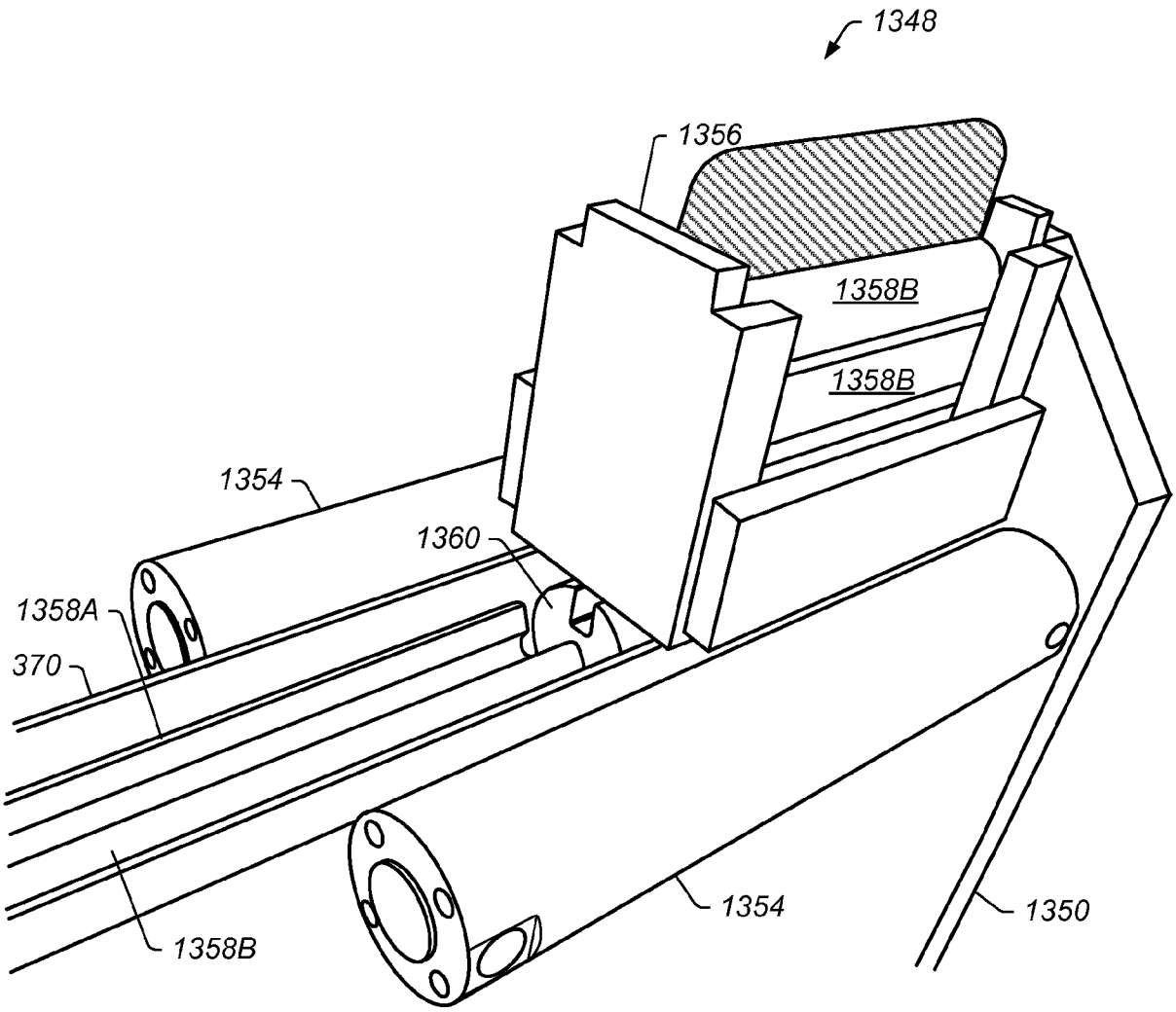


FIG. 58

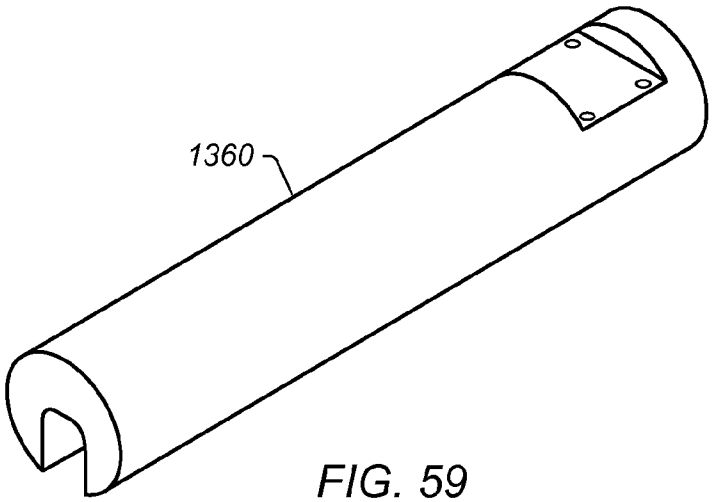


FIG. 59

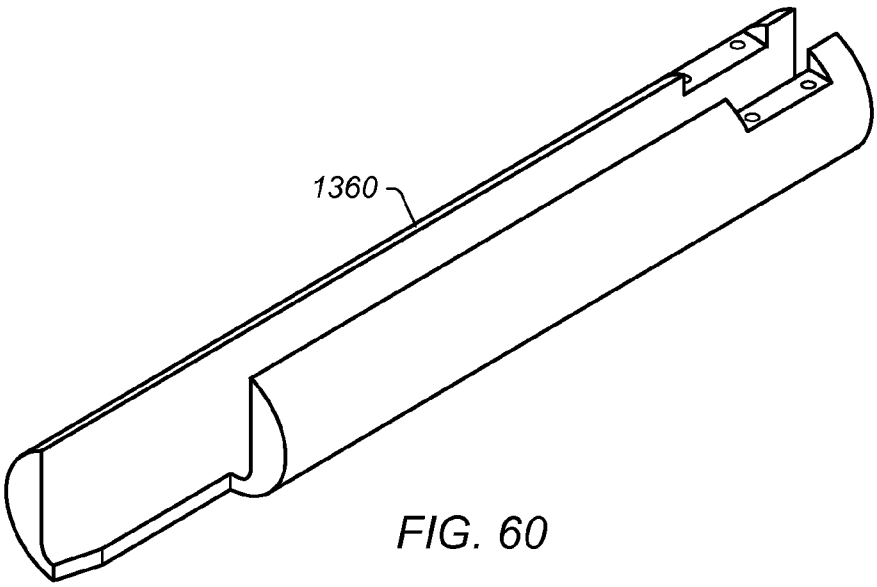


FIG. 60

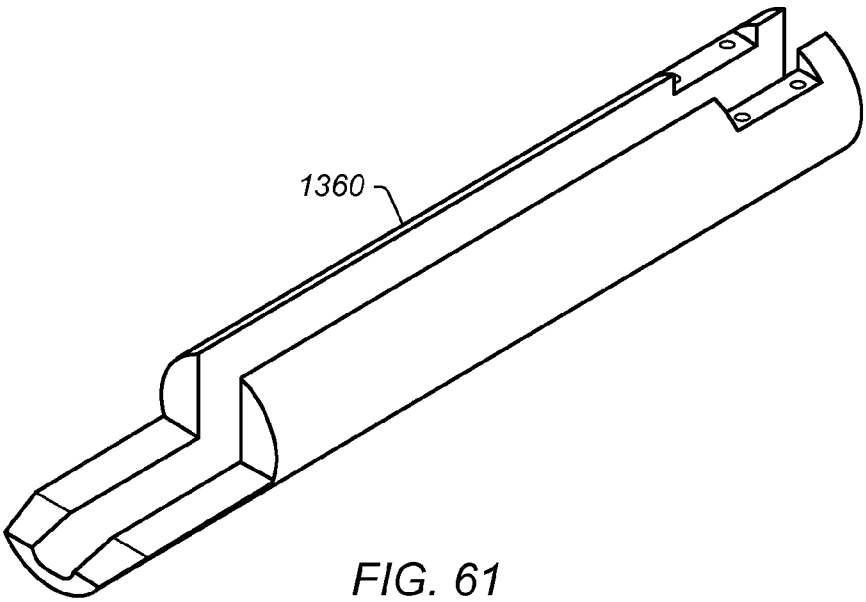


FIG. 61

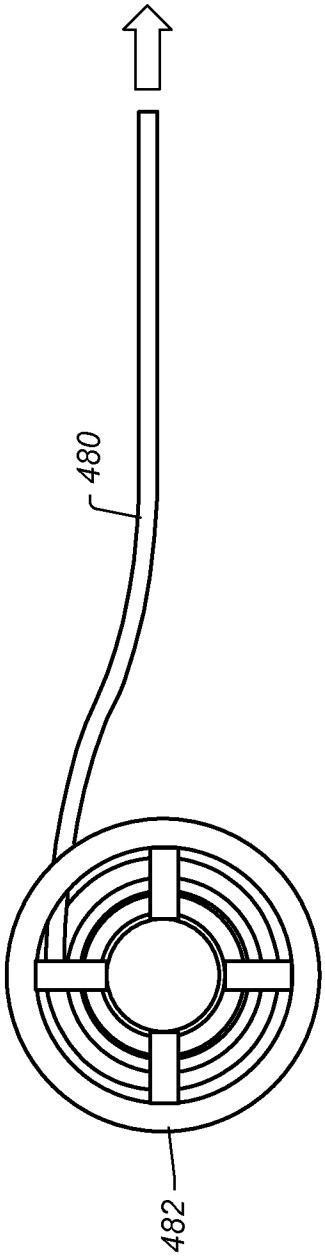


FIG. 62

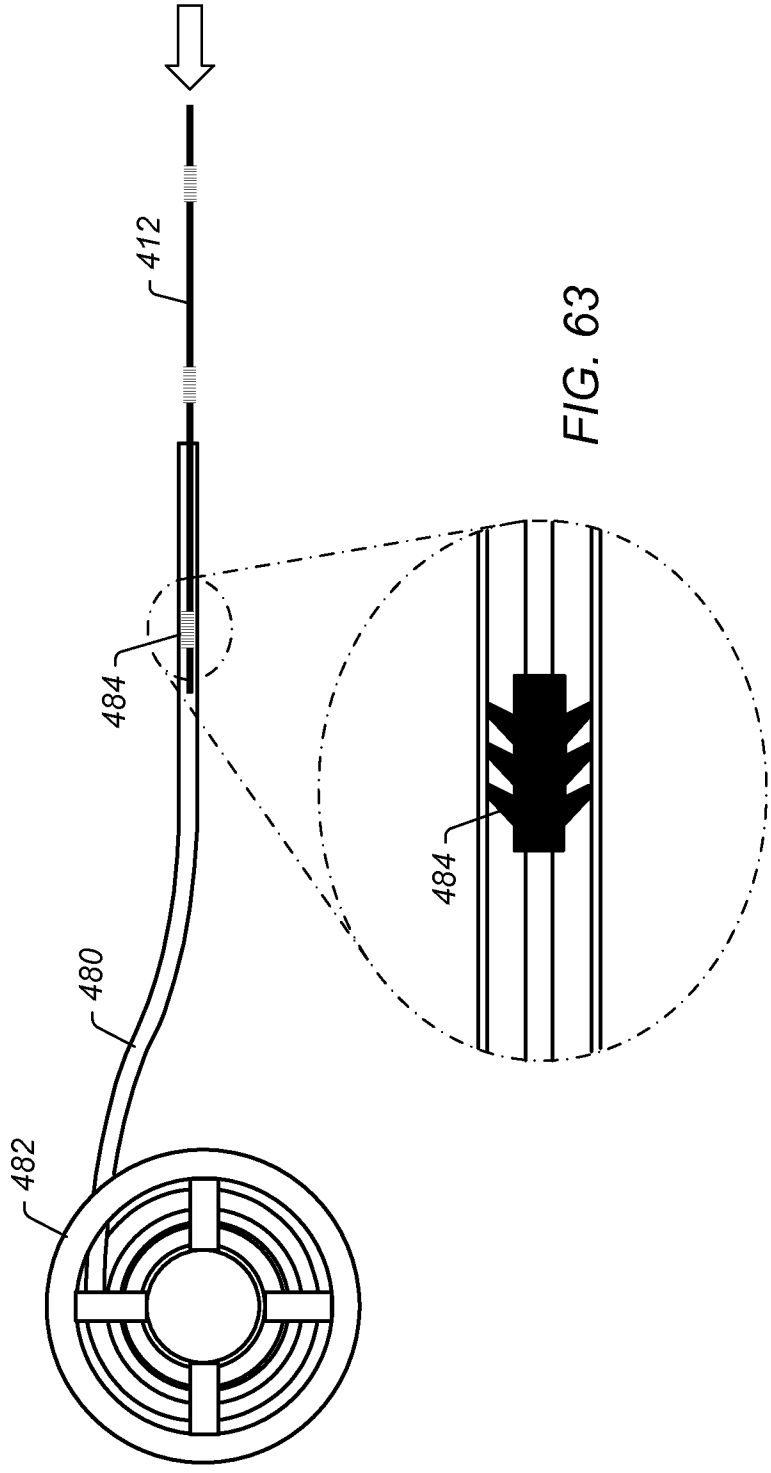


FIG. 63

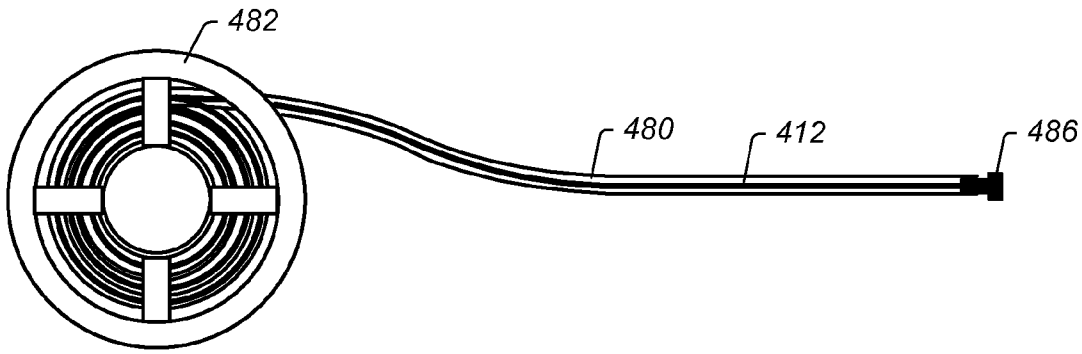


FIG. 64

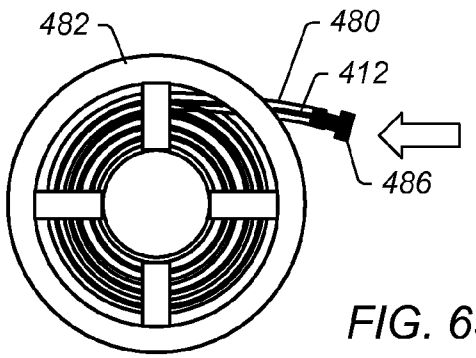


FIG. 65

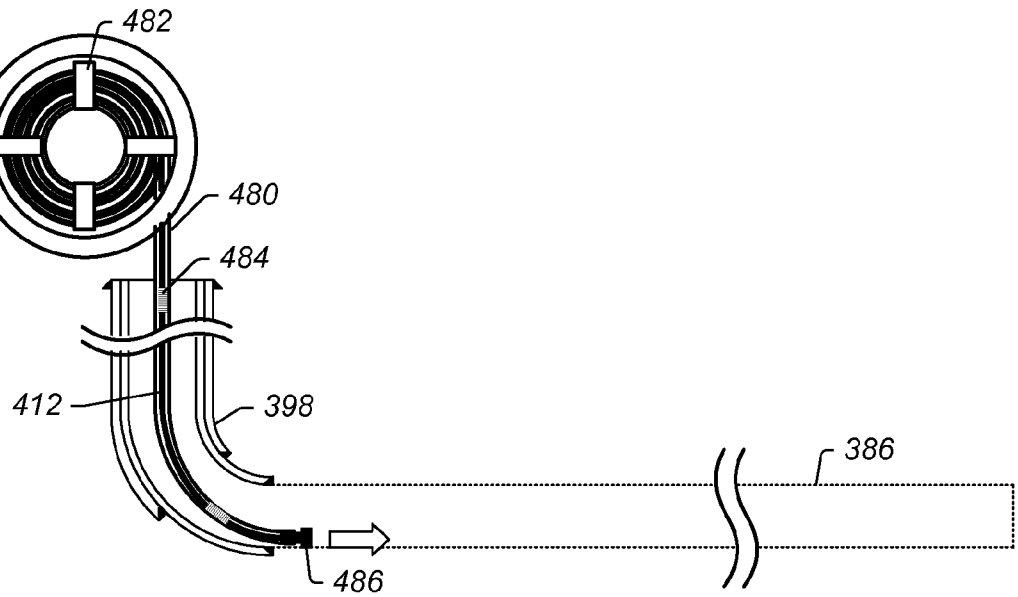


FIG. 66

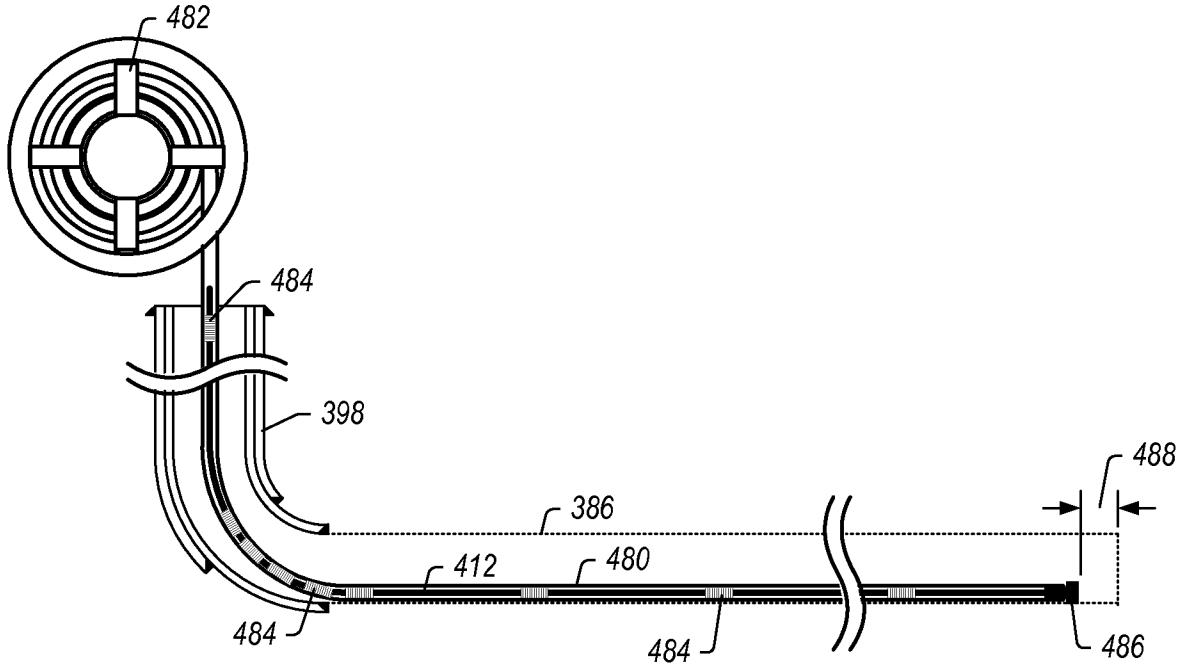

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FIG. 67

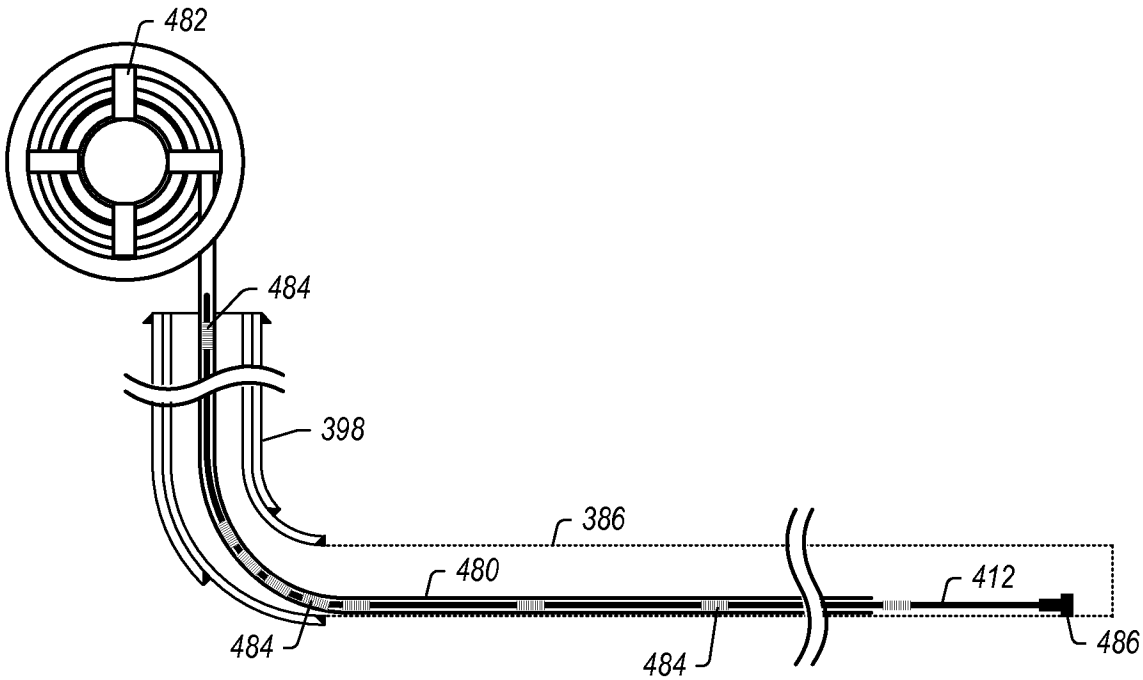

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FIG. 68

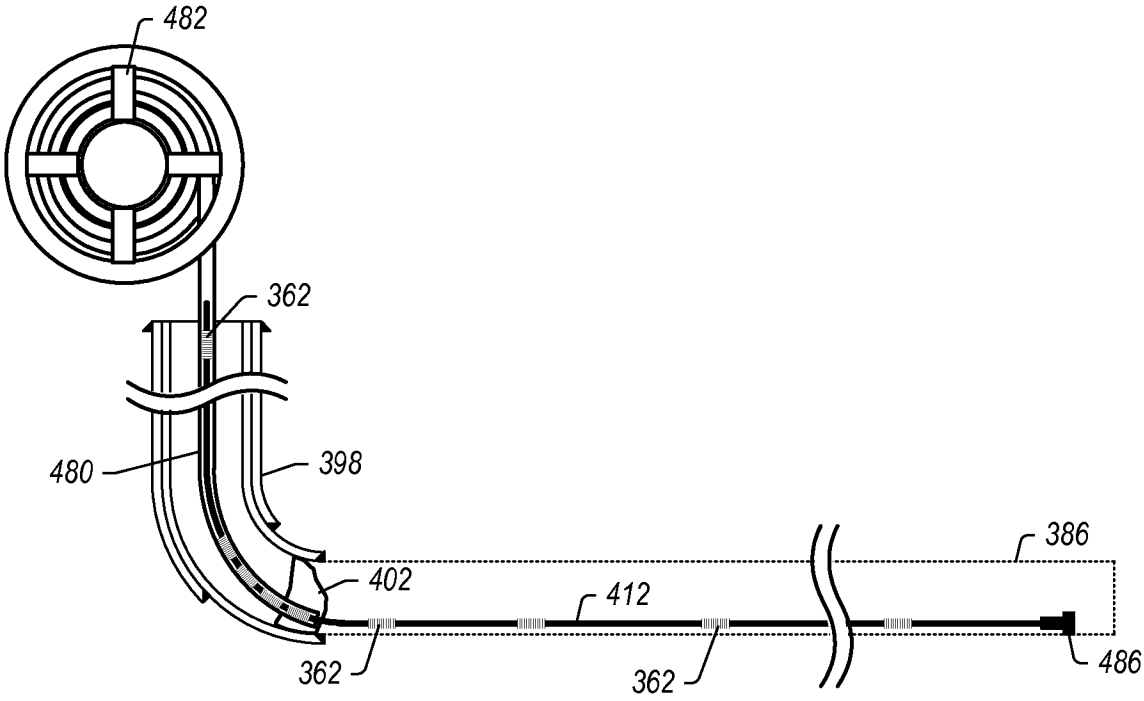

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FIG. 69

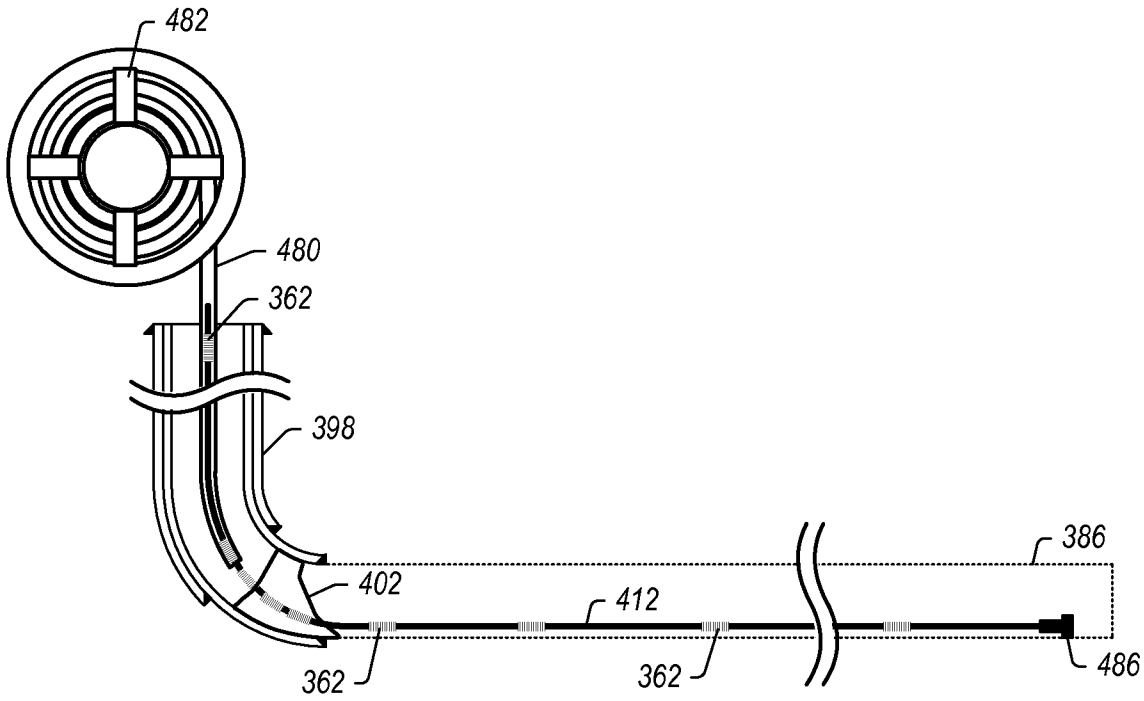

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FIG. 70

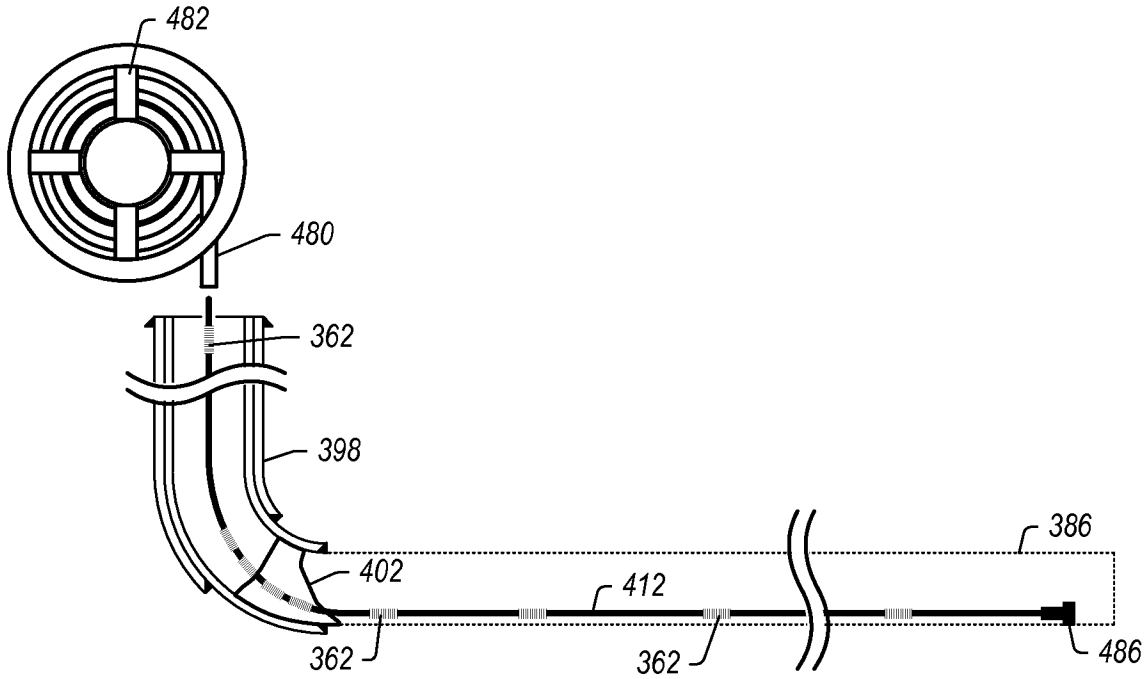

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FIG. 71

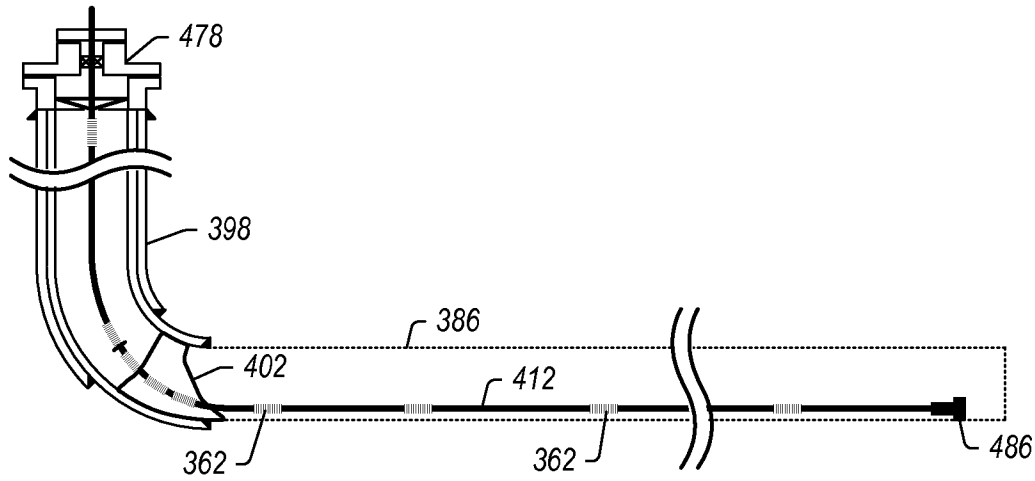

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FIG. 72

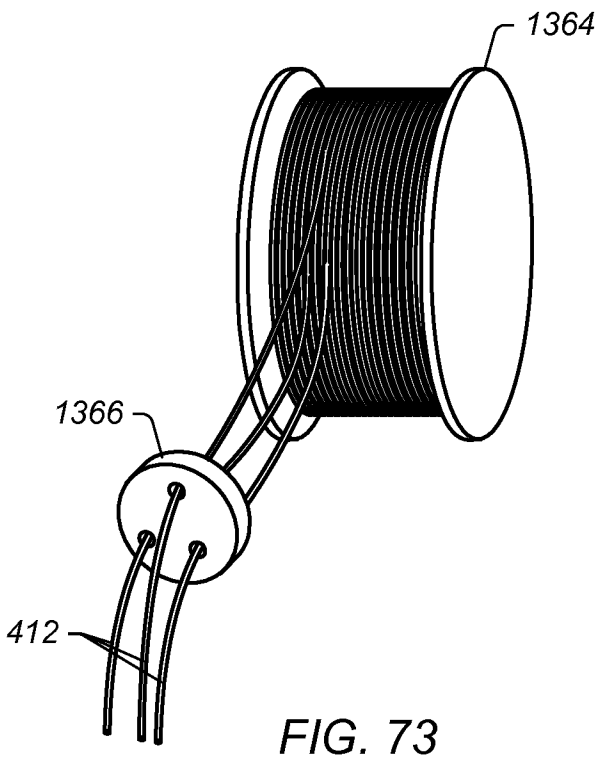


FIG. 73

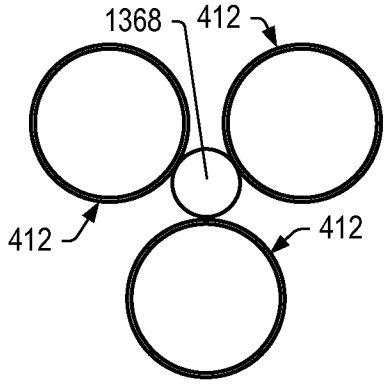


FIG. 75

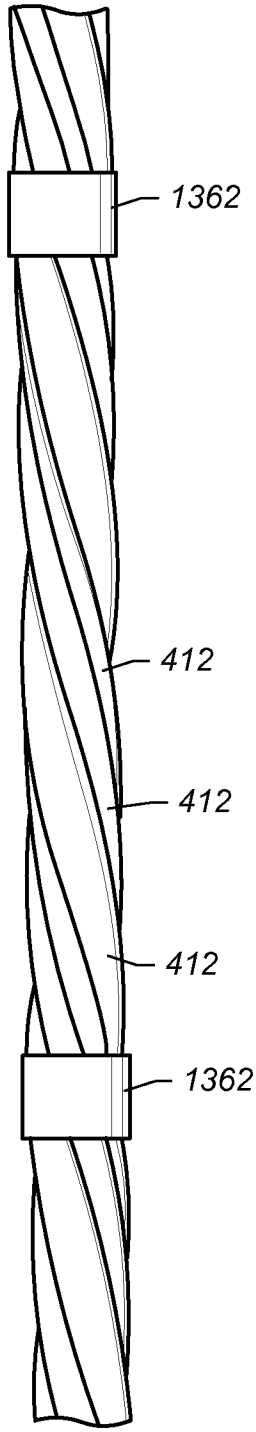


FIG. 74

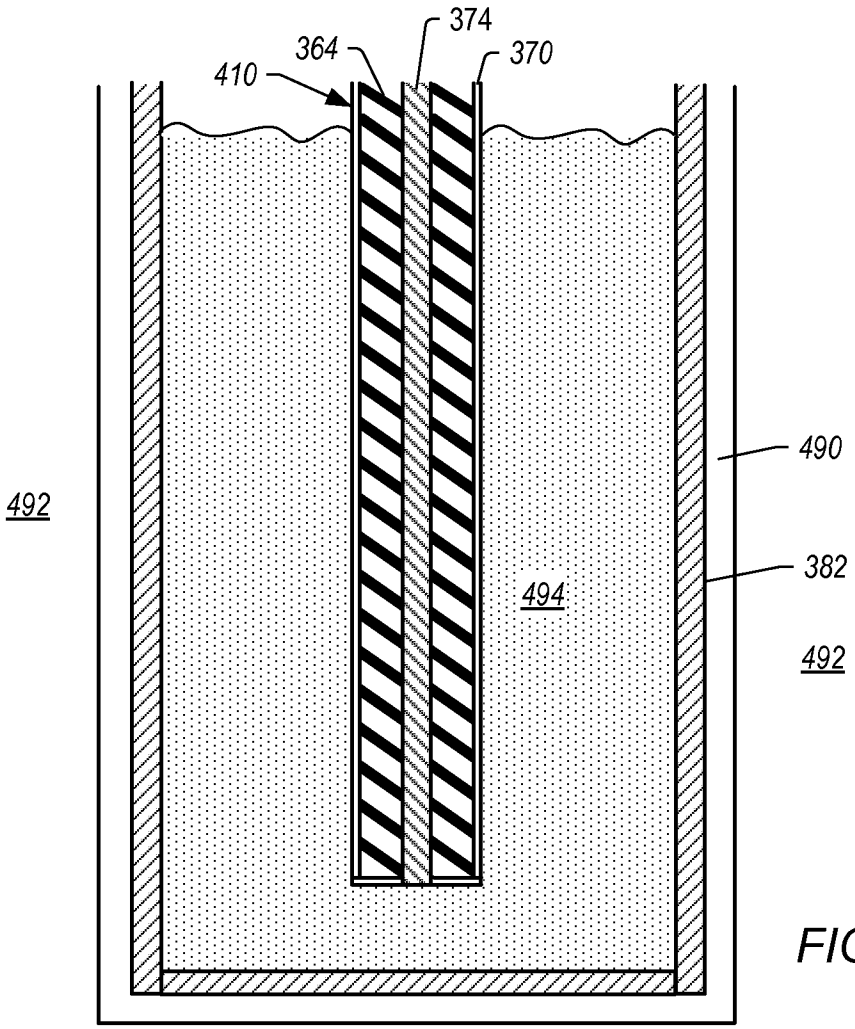

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FIG. 76

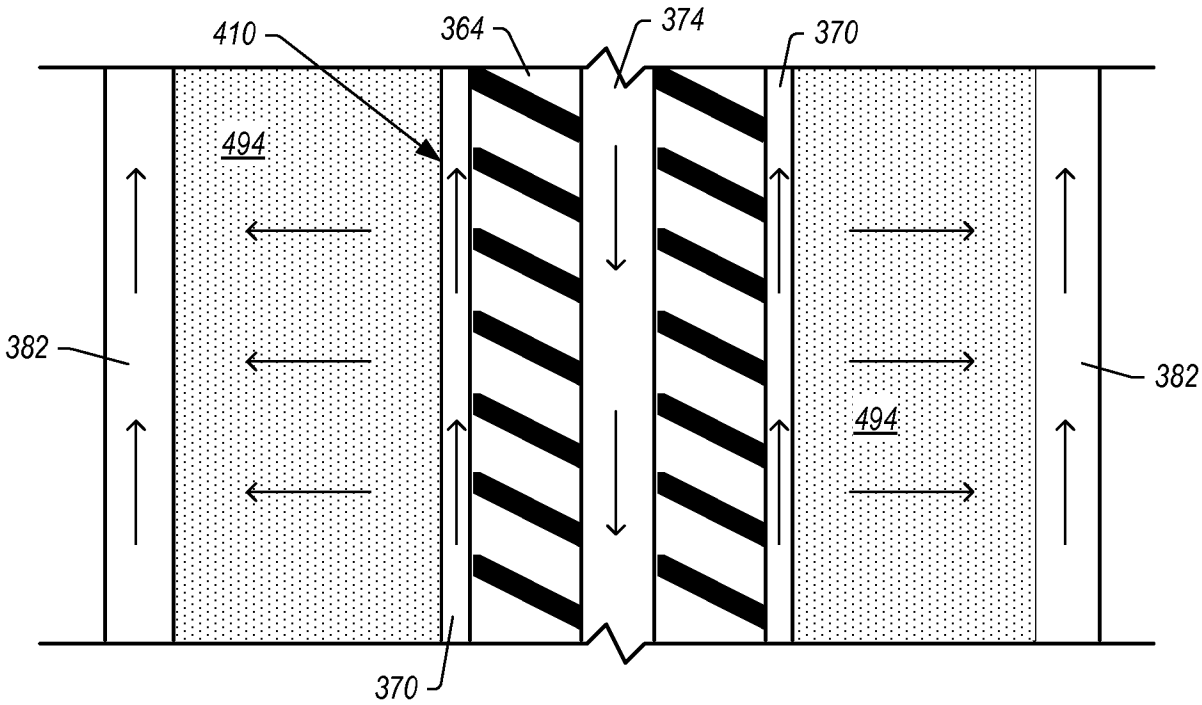

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FIG. 77

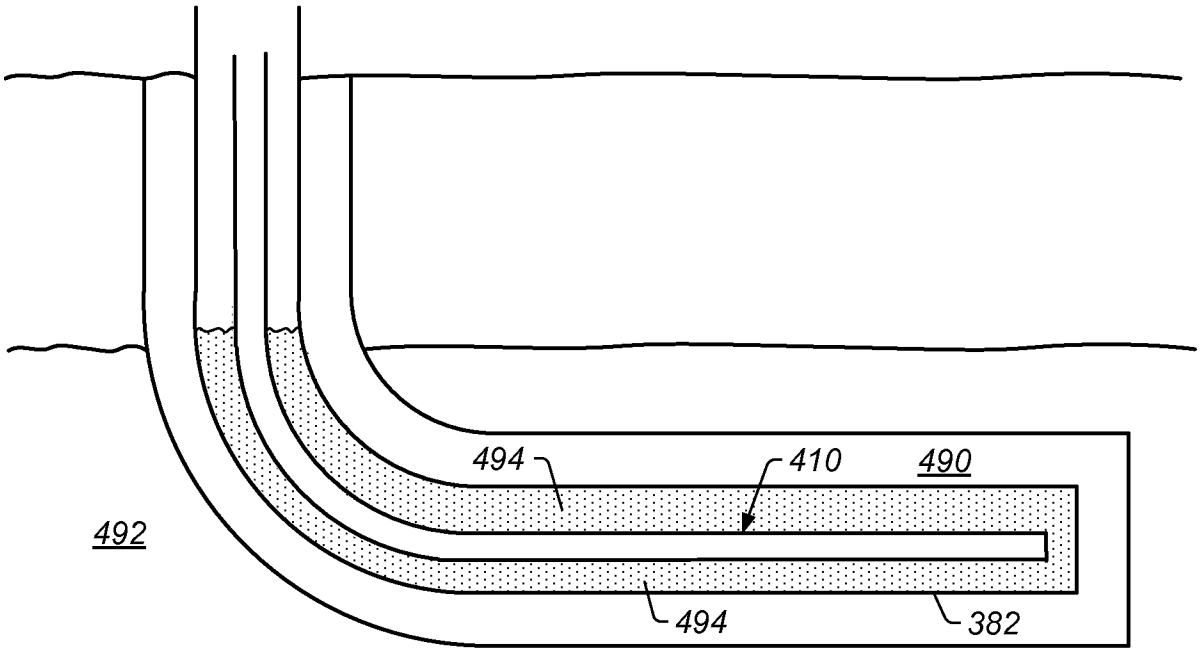


FIG. 78

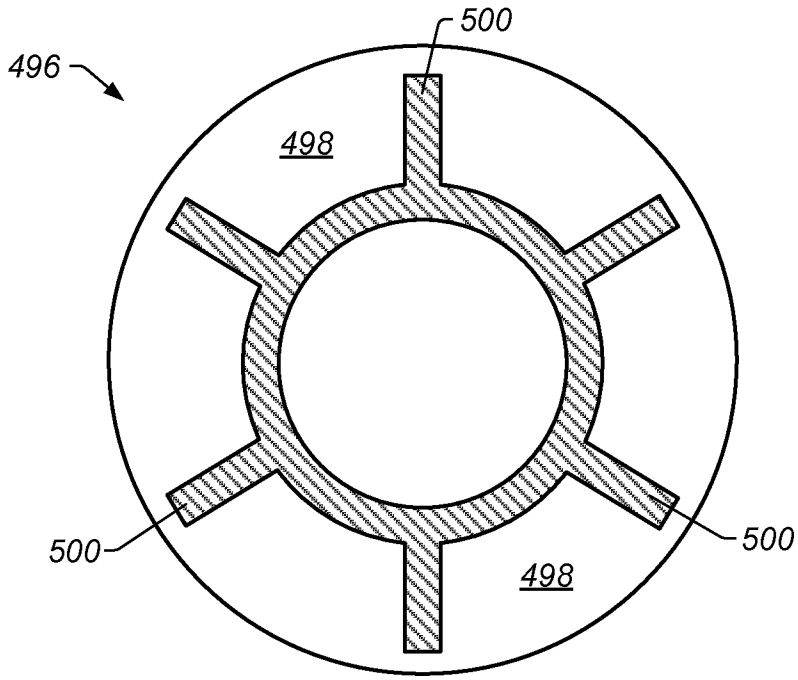


FIG. 79

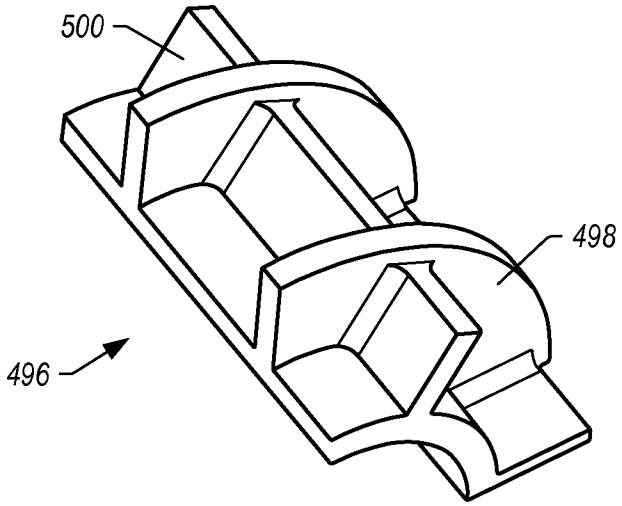


FIG. 80

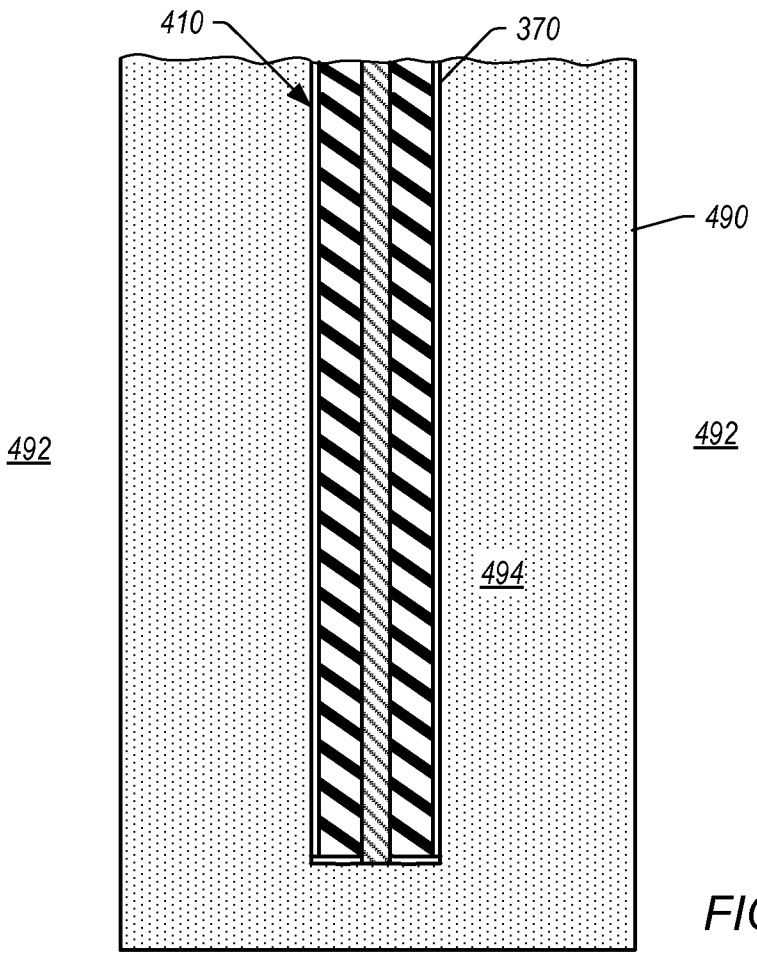


FIG. 81

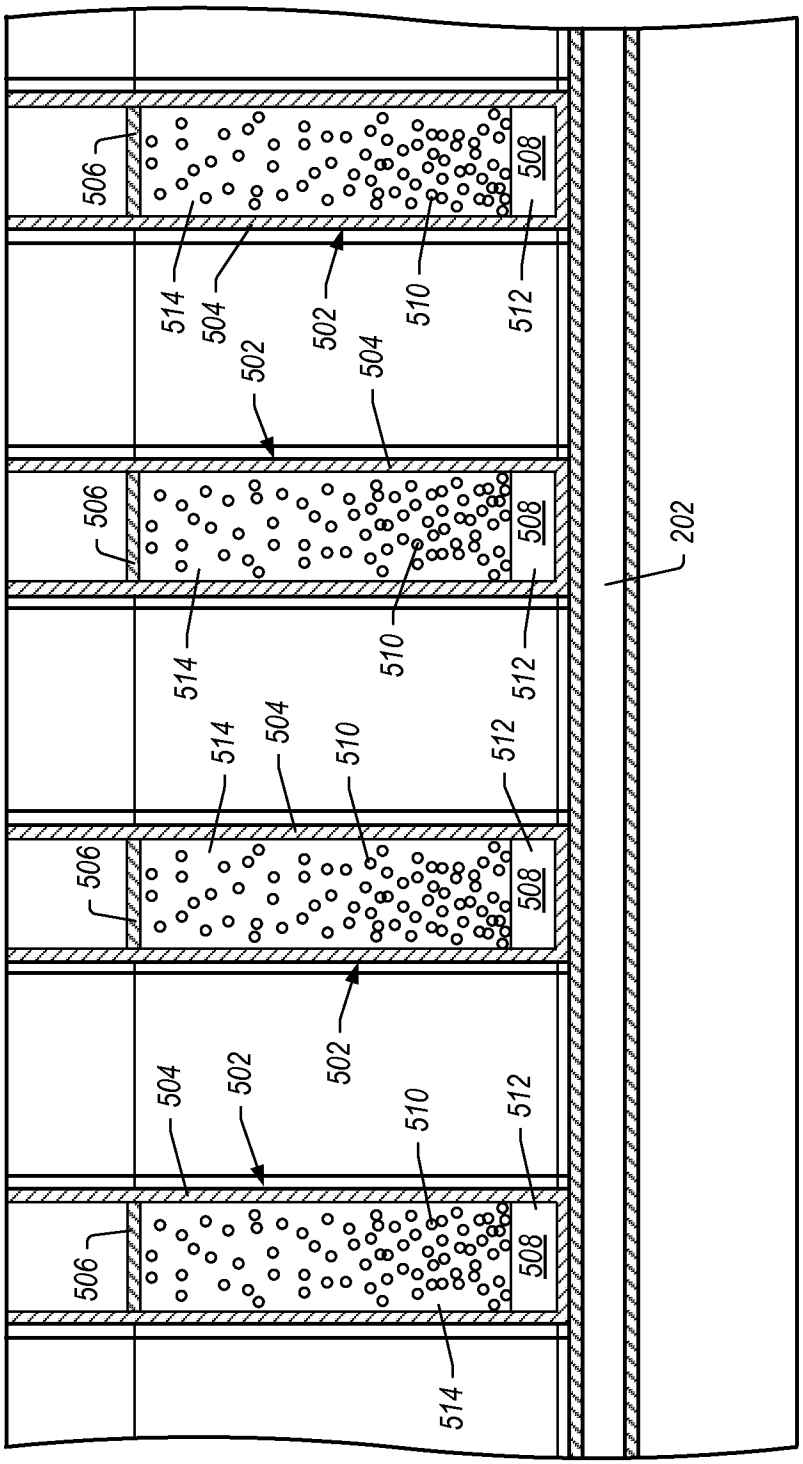


FIG. 82

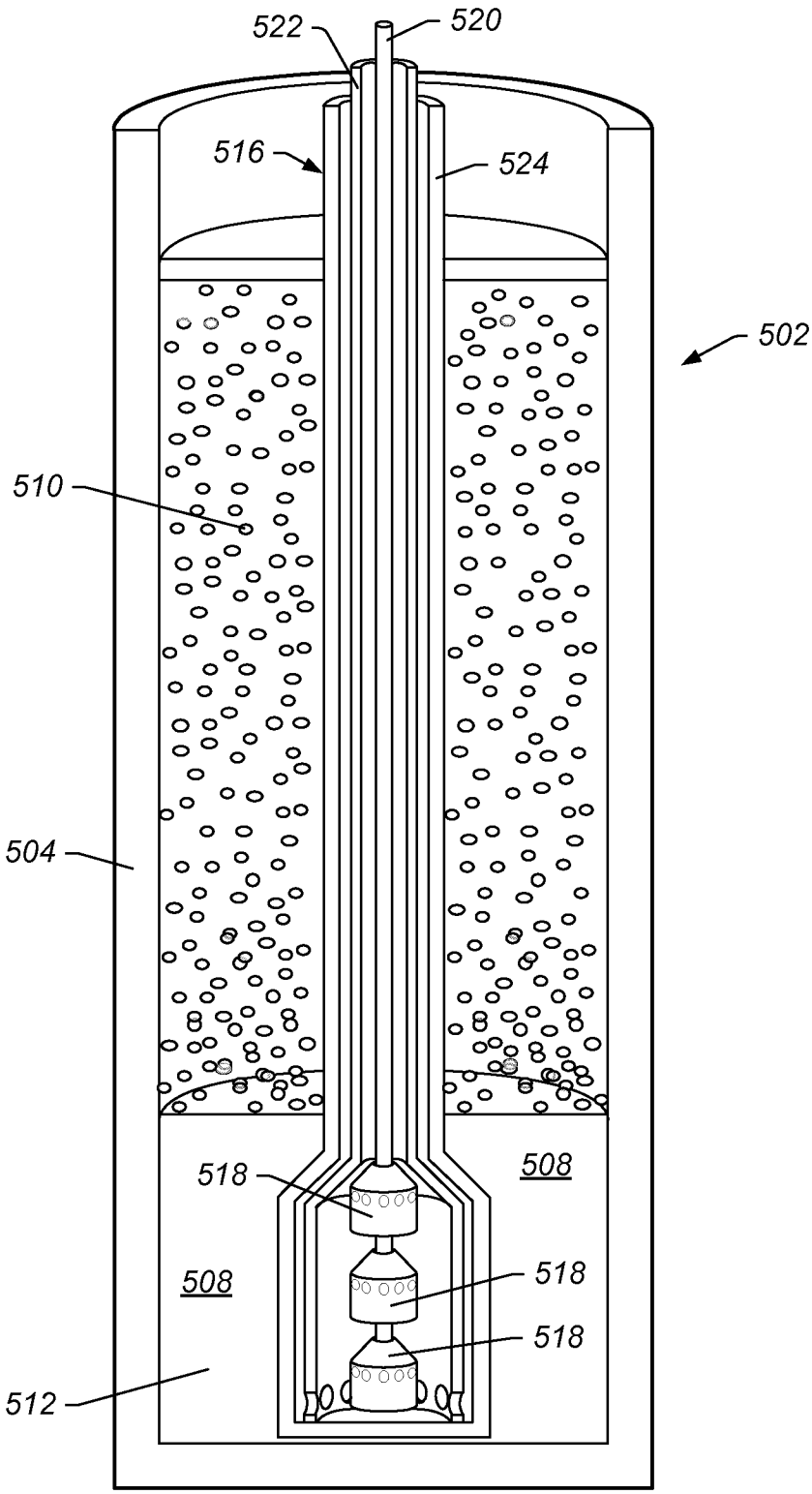


FIG. 83

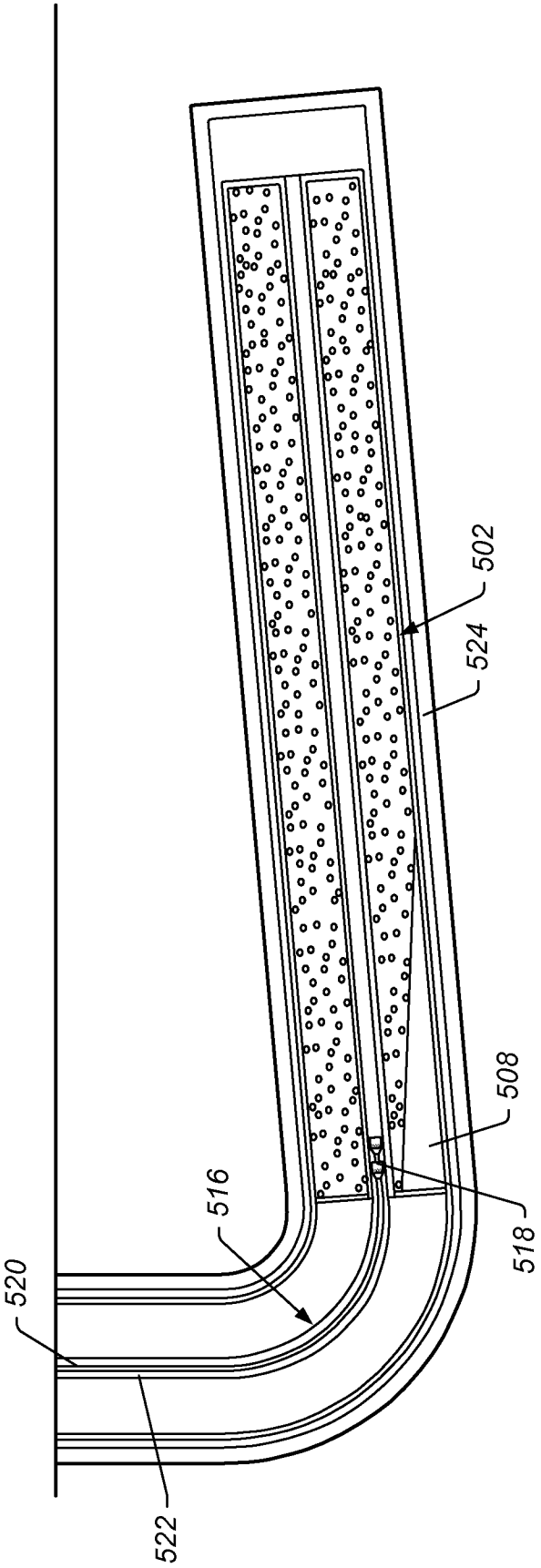


FIG. 84

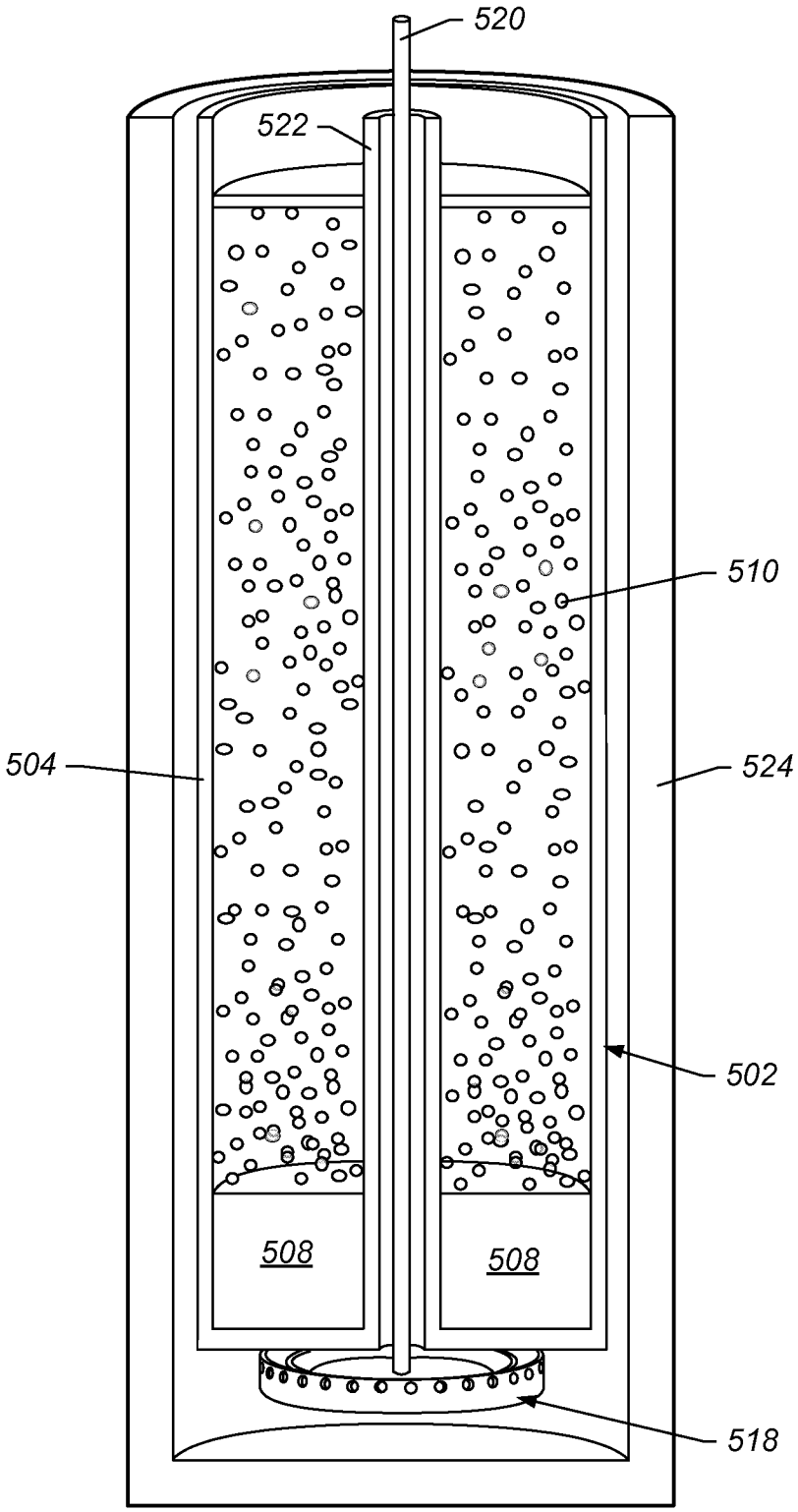


FIG. 85

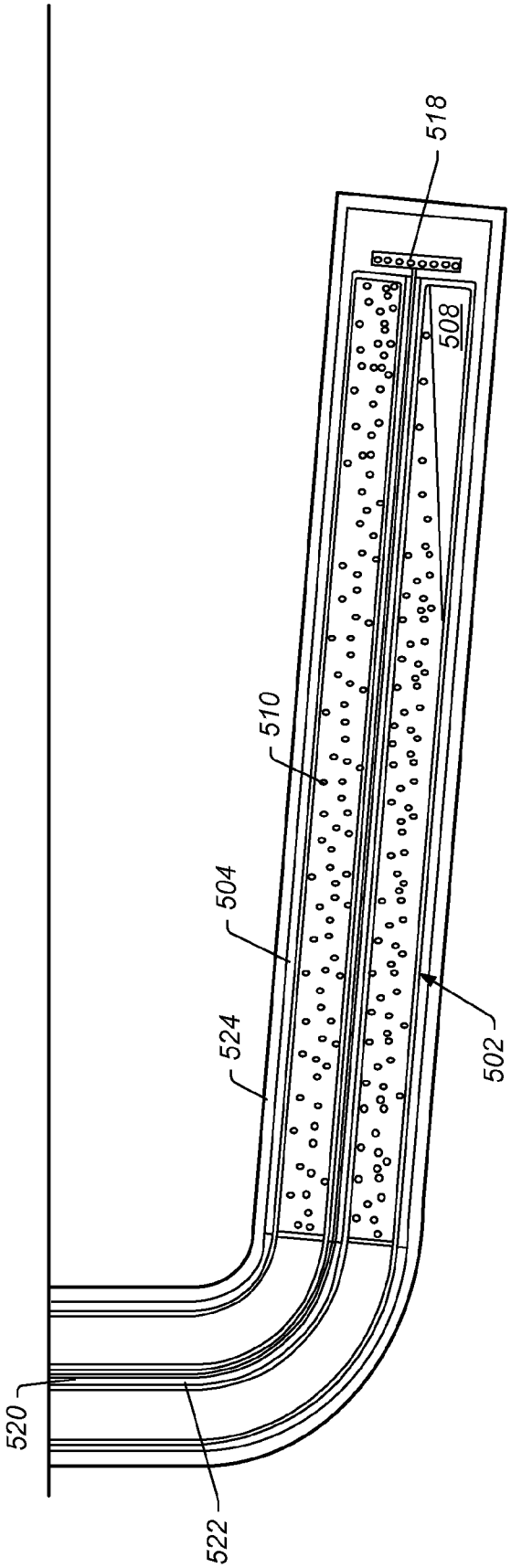


FIG. 86

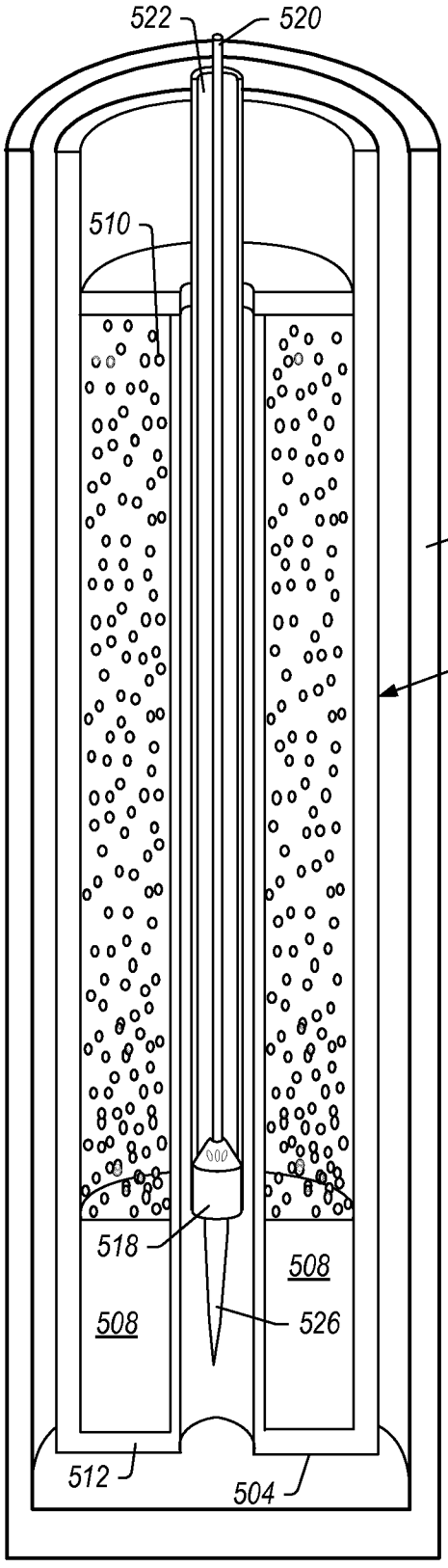

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FIG. 87

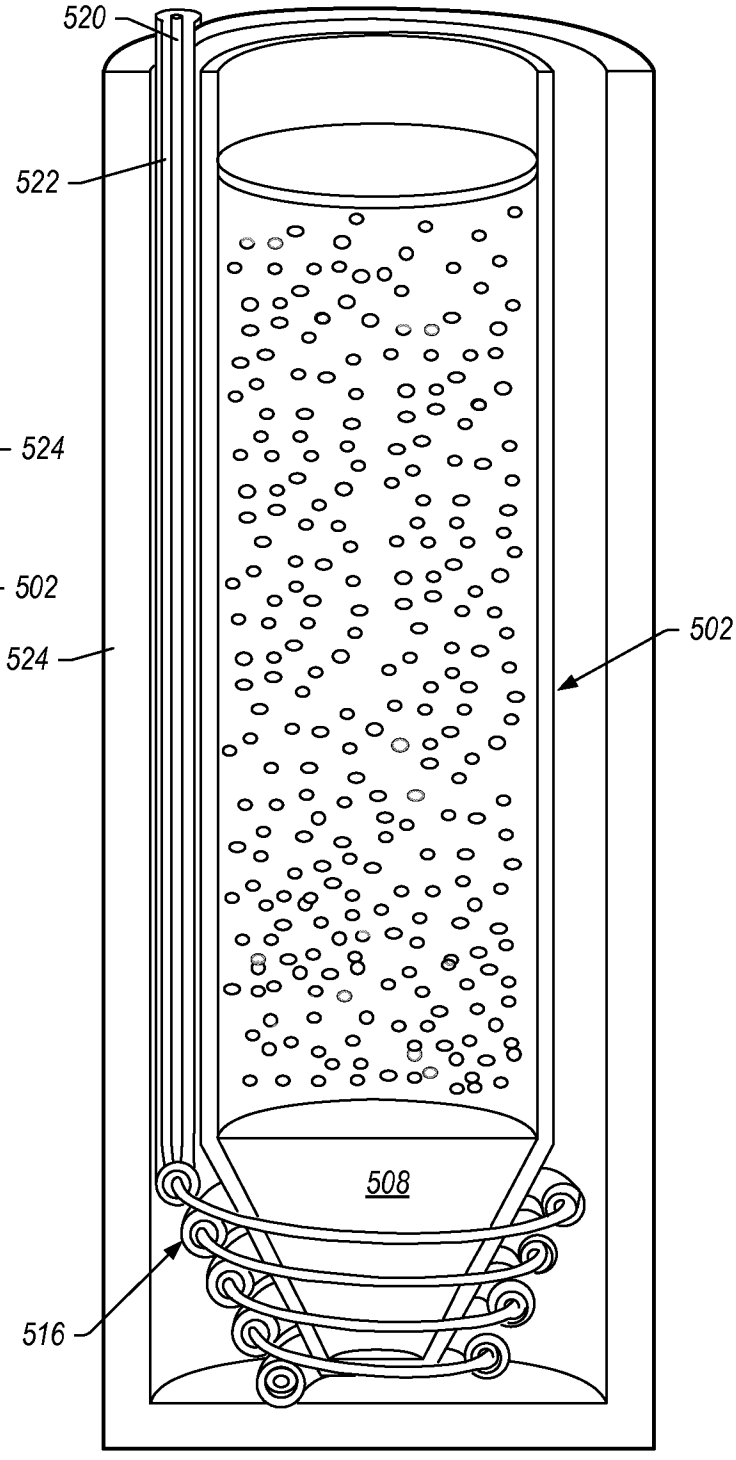

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FIG. 88

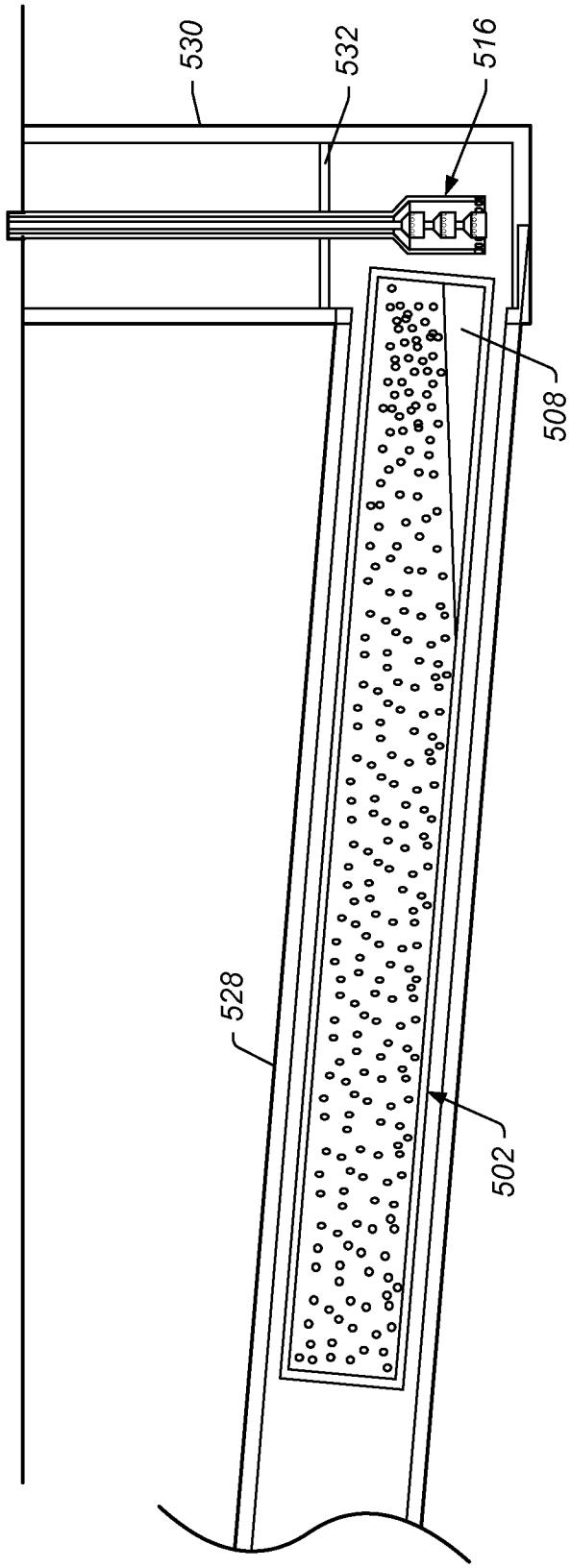


FIG. 89

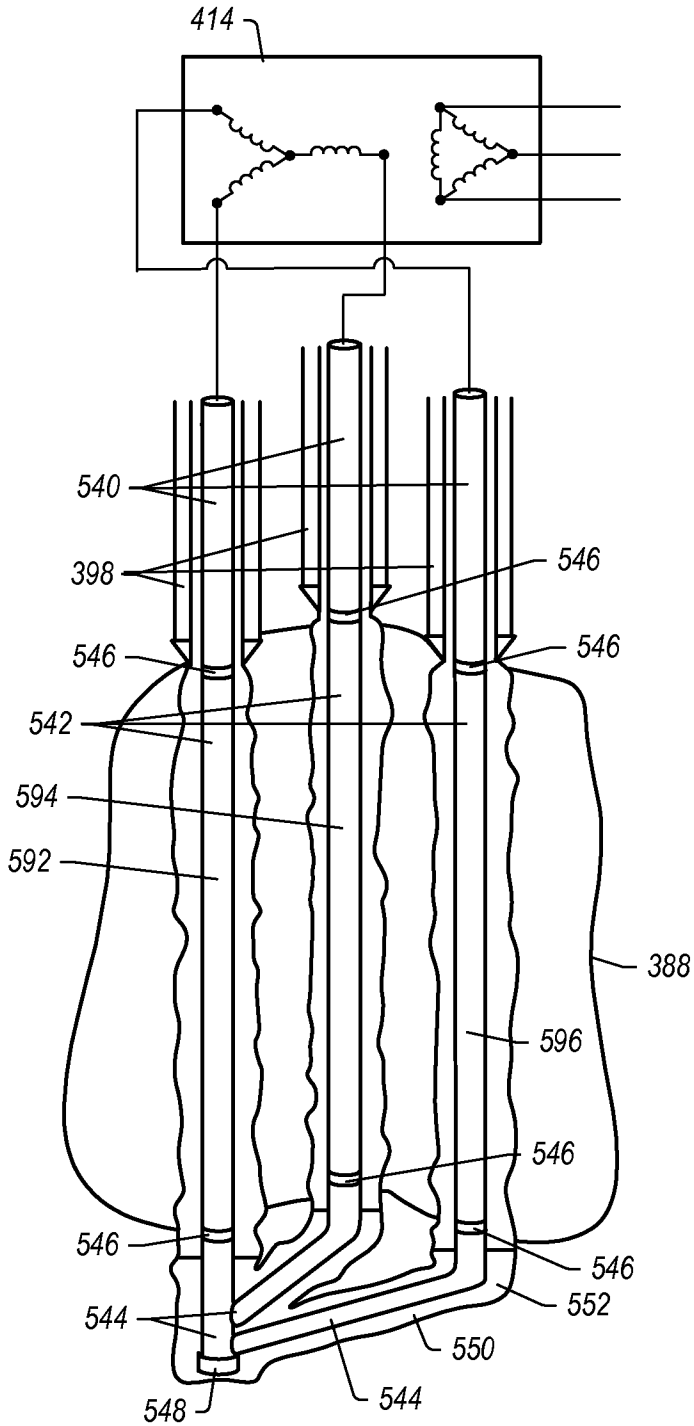

414
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398
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542
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388
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544
548

FIG. 90

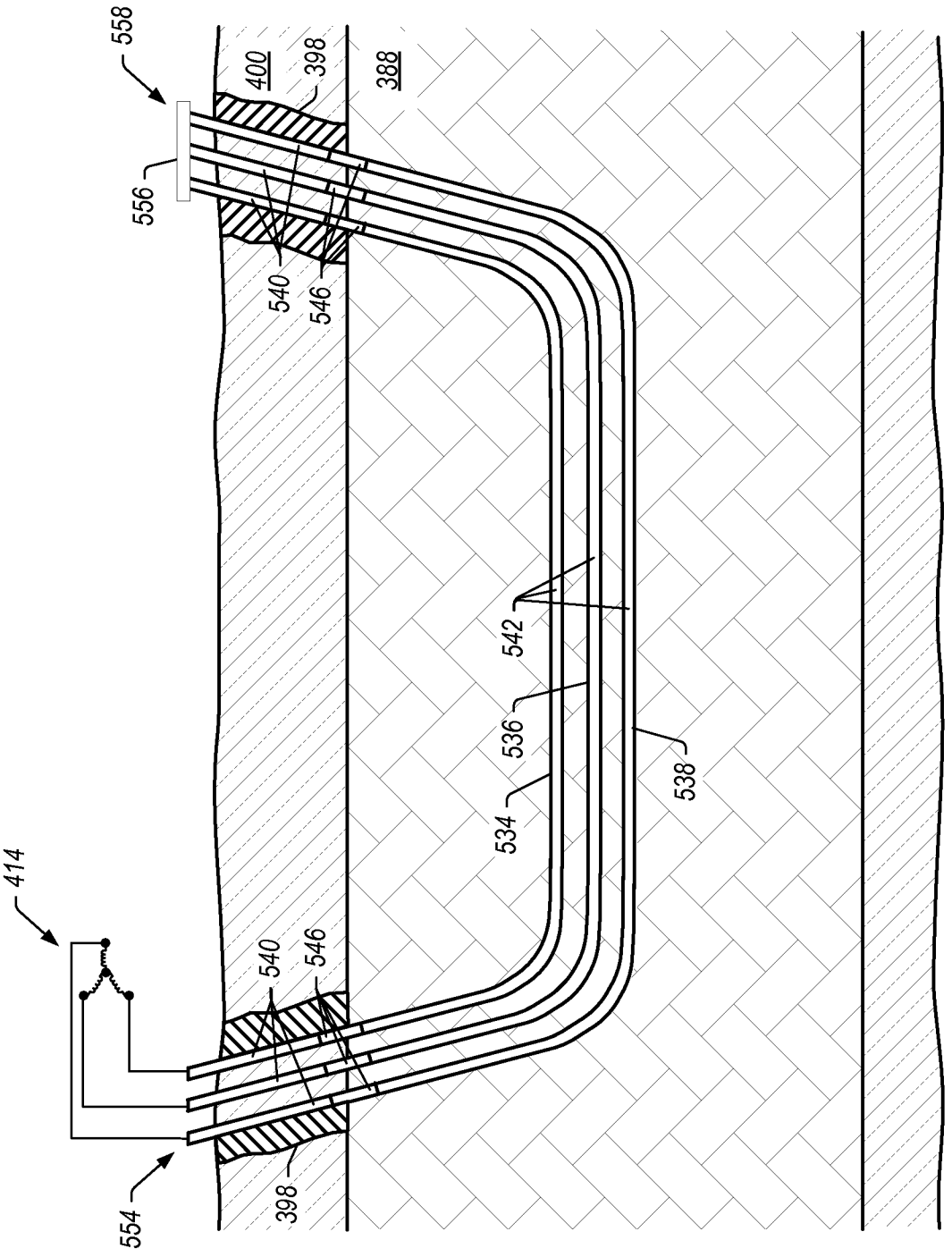


FIG. 91

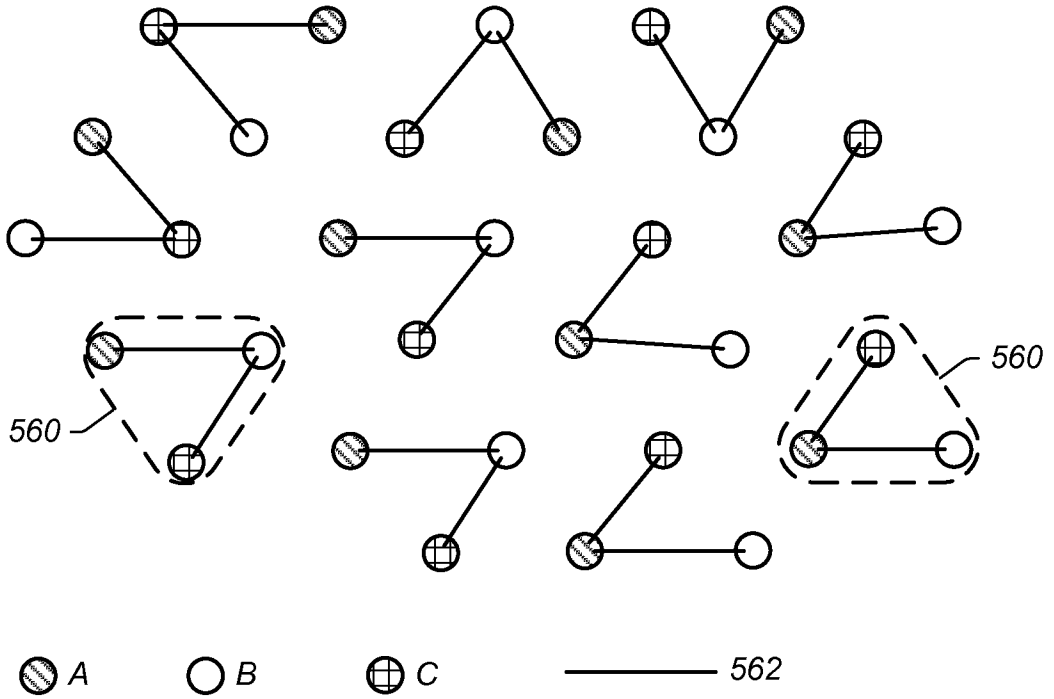


FIG. 92

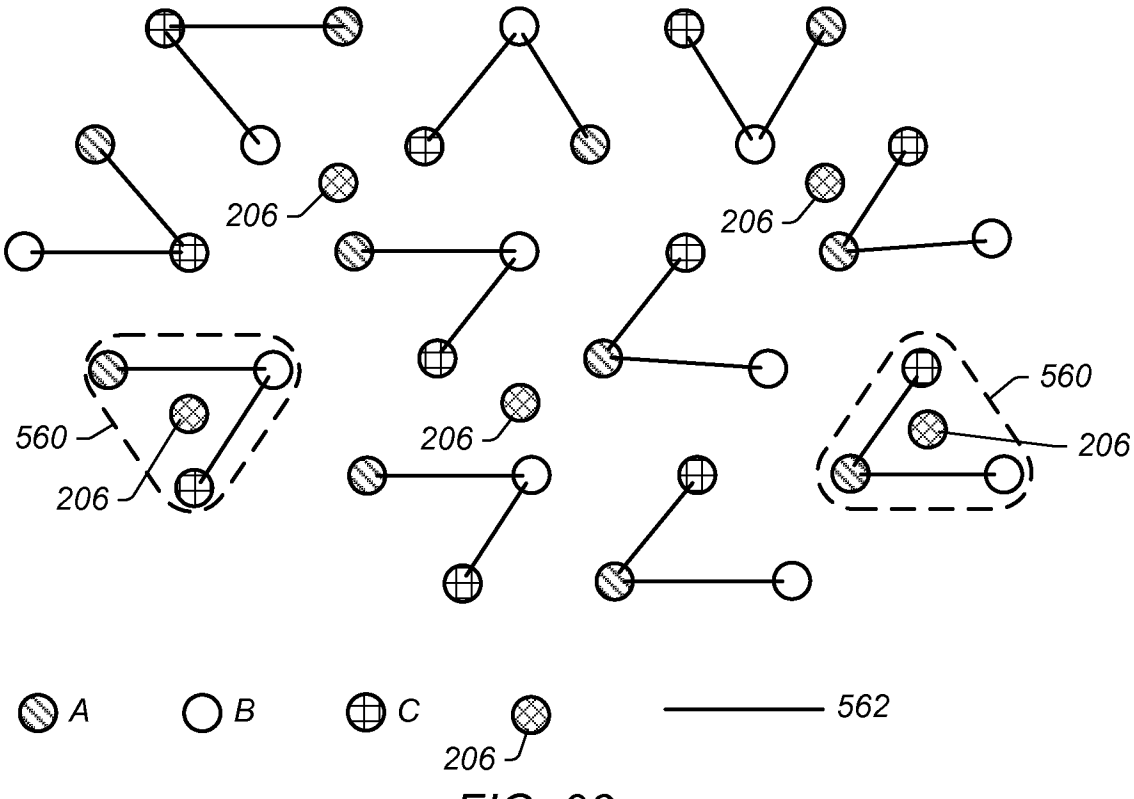


FIG. 93

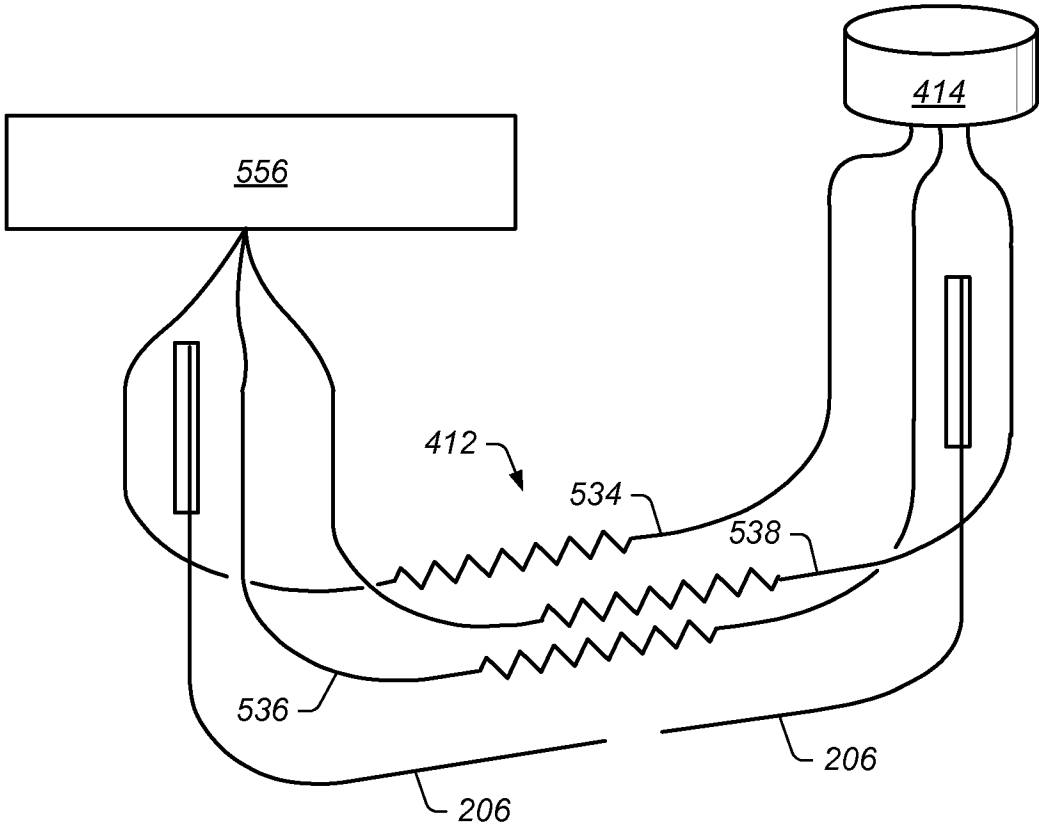


FIG. 94

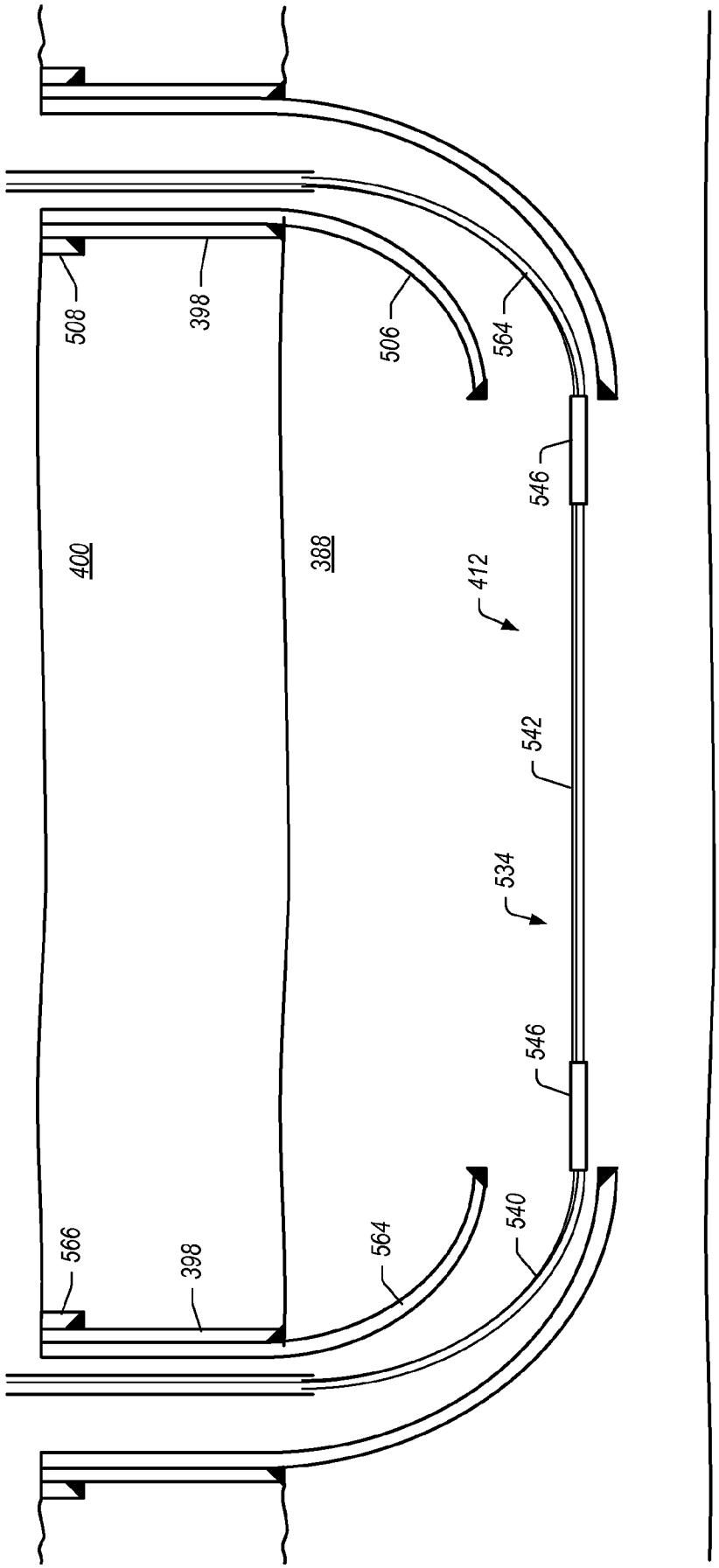


FIG. 95

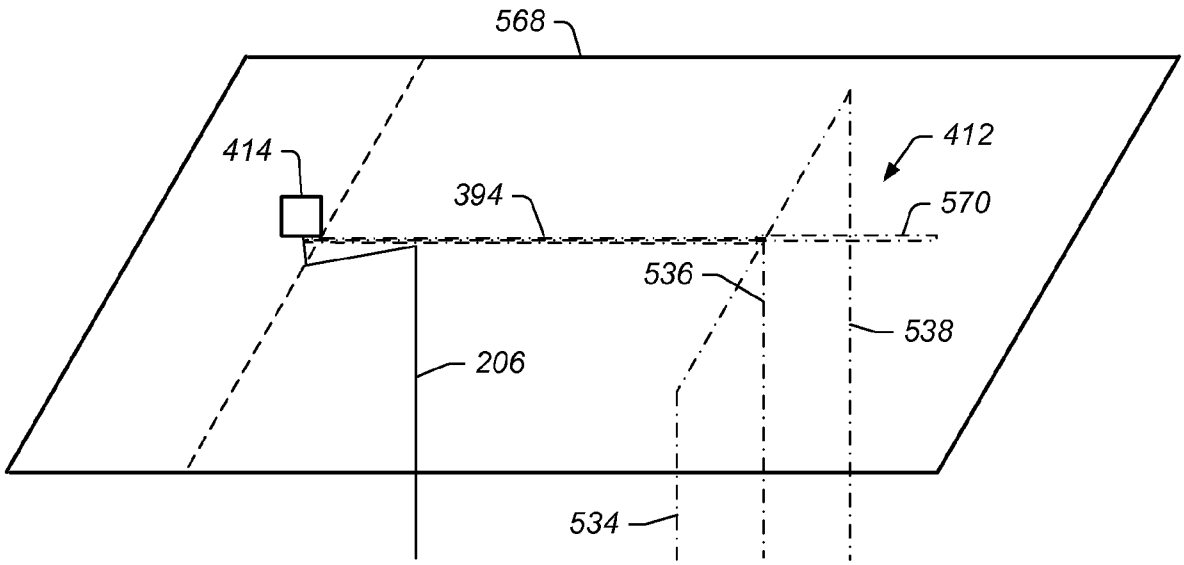


FIG. 96

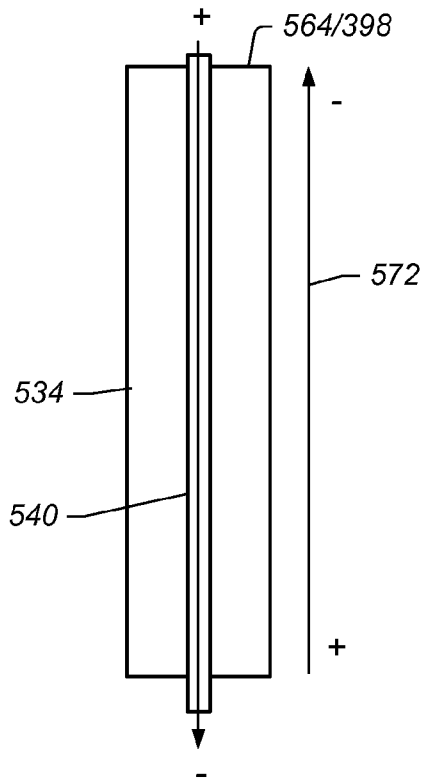


FIG. 97

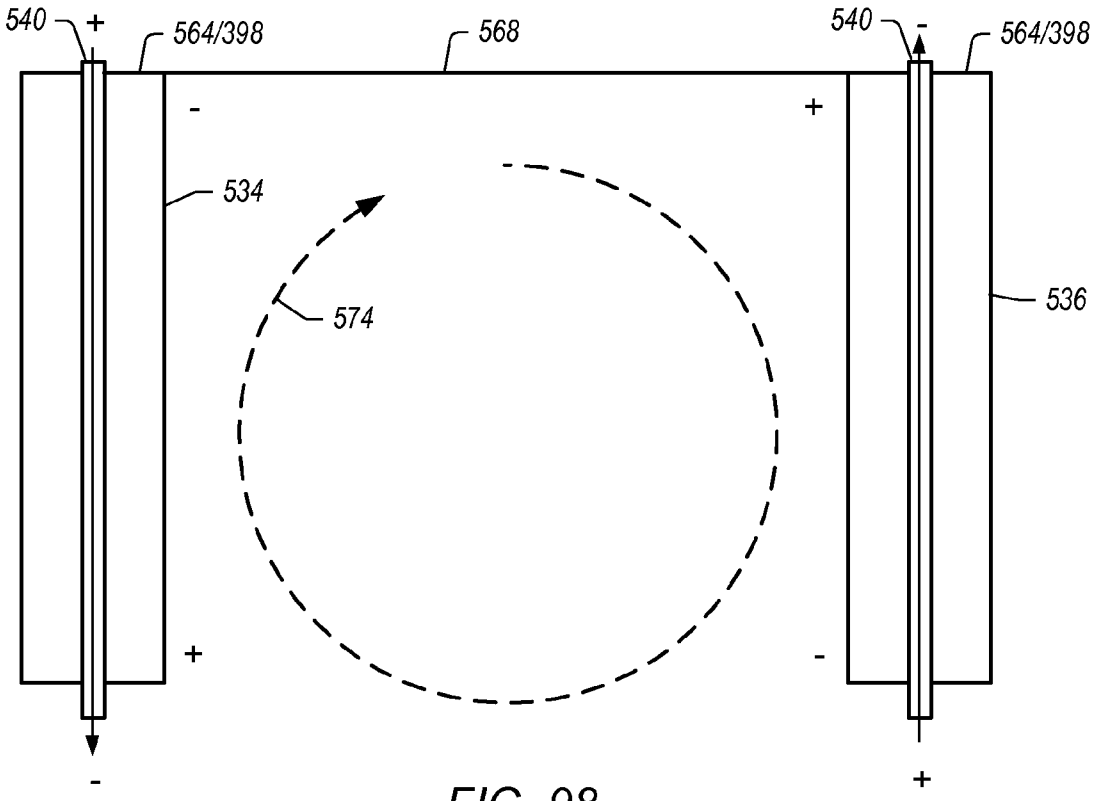

540
+
564/398
568
540
-
564/398
-
+
534
574
536
+
-
-
+

FIG. 98

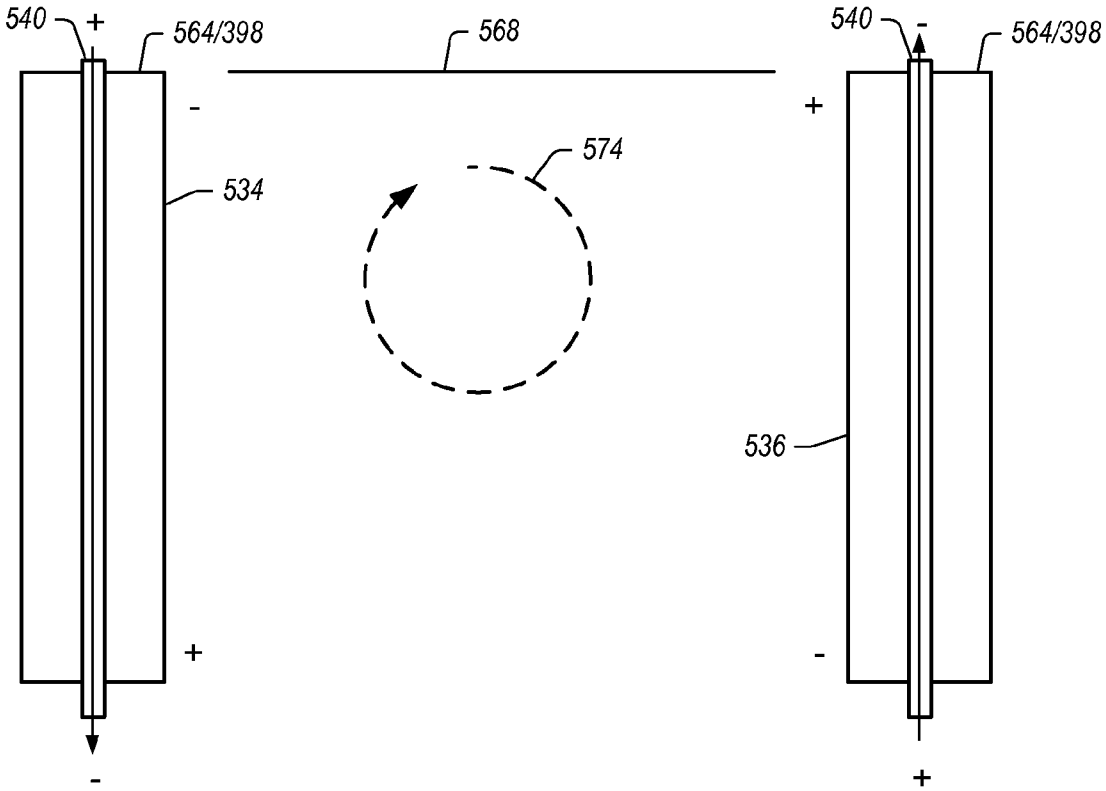

540
+
564/398
568
540
-
564/398
-
+
534
574
536
+
-
-
+

FIG. 99

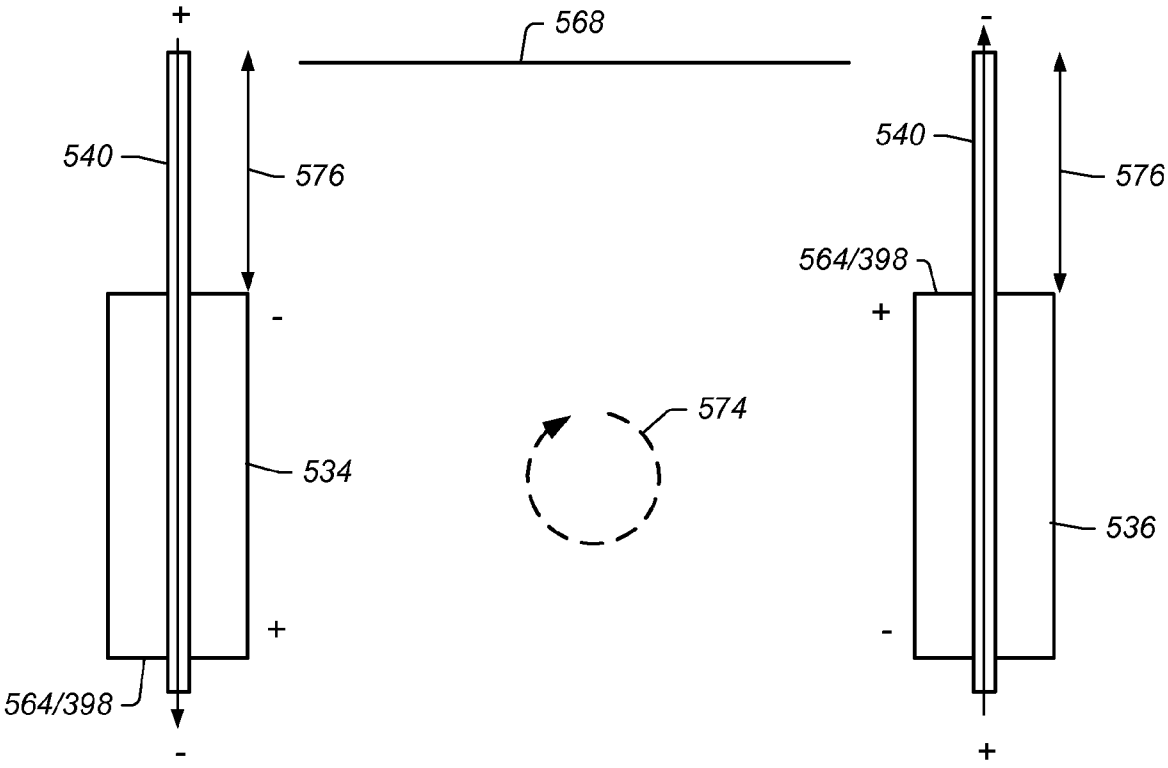


FIG. 100

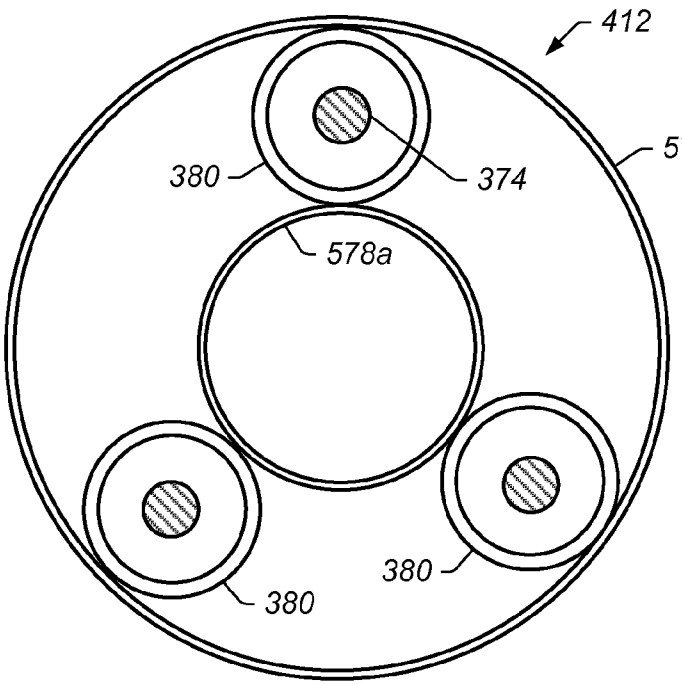


FIG. 101

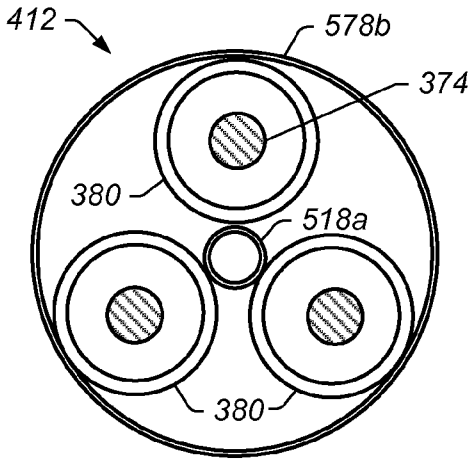


FIG. 102

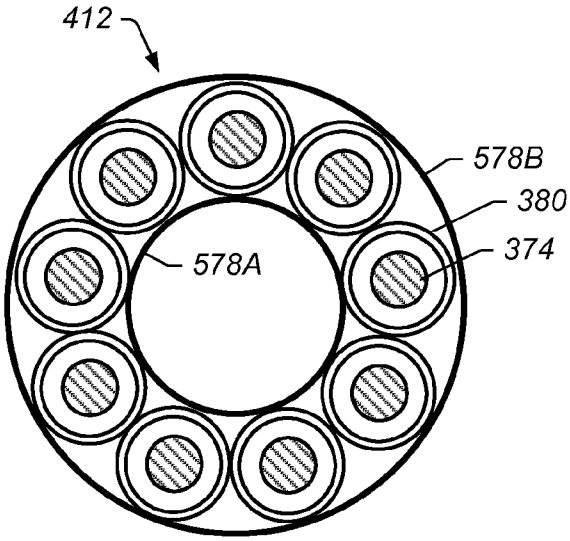


FIG. 103

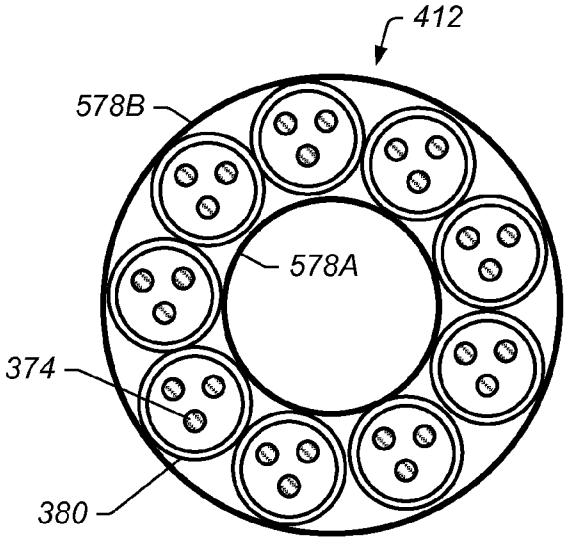


FIG. 104

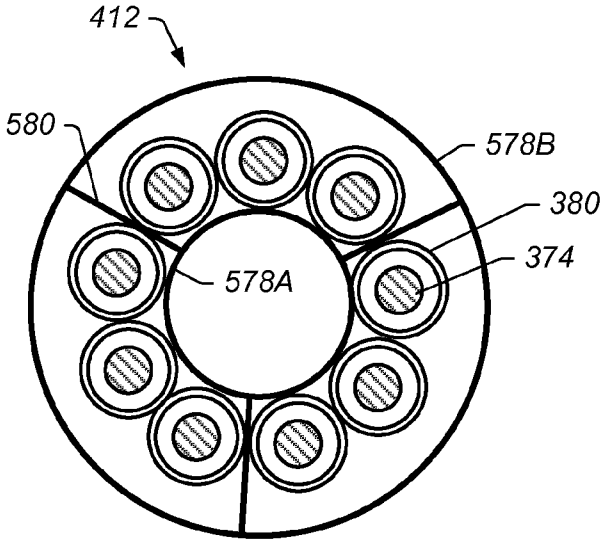


FIG. 105

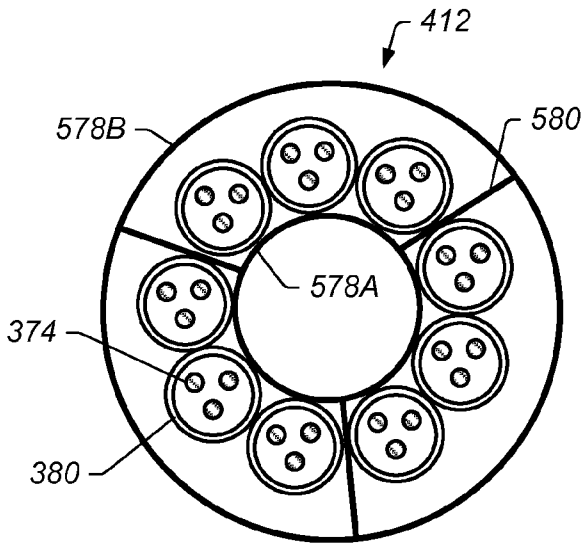


FIG. 106

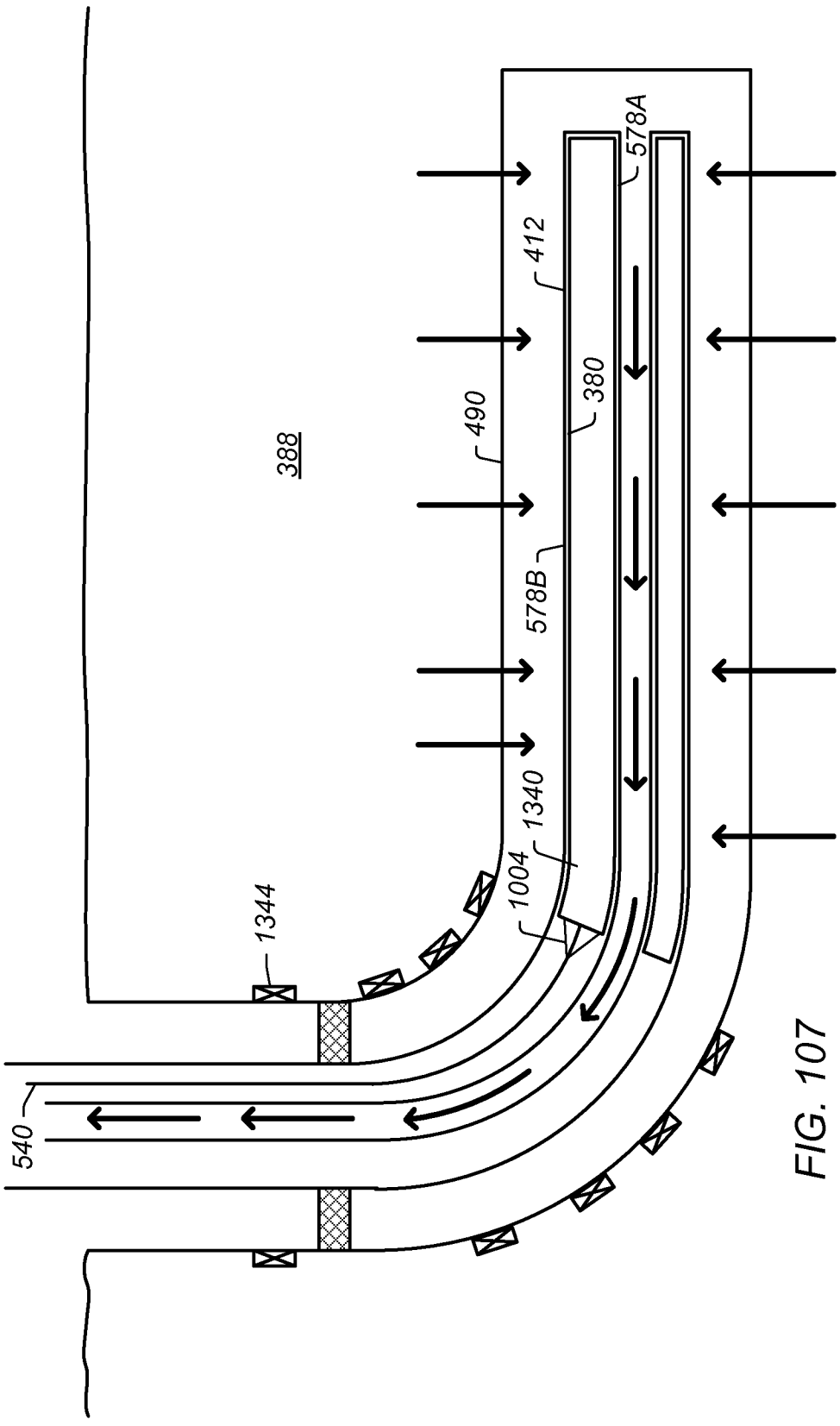


FIG. 107

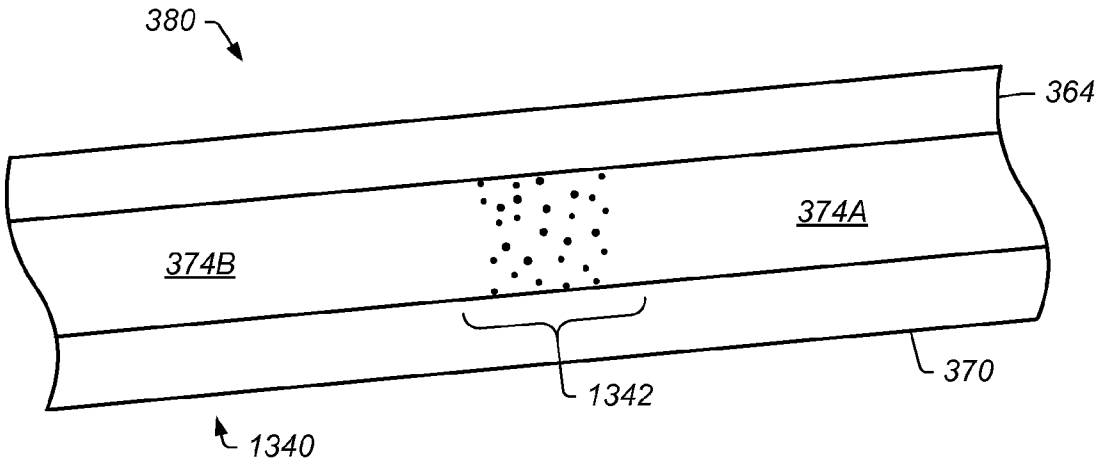


FIG. 108

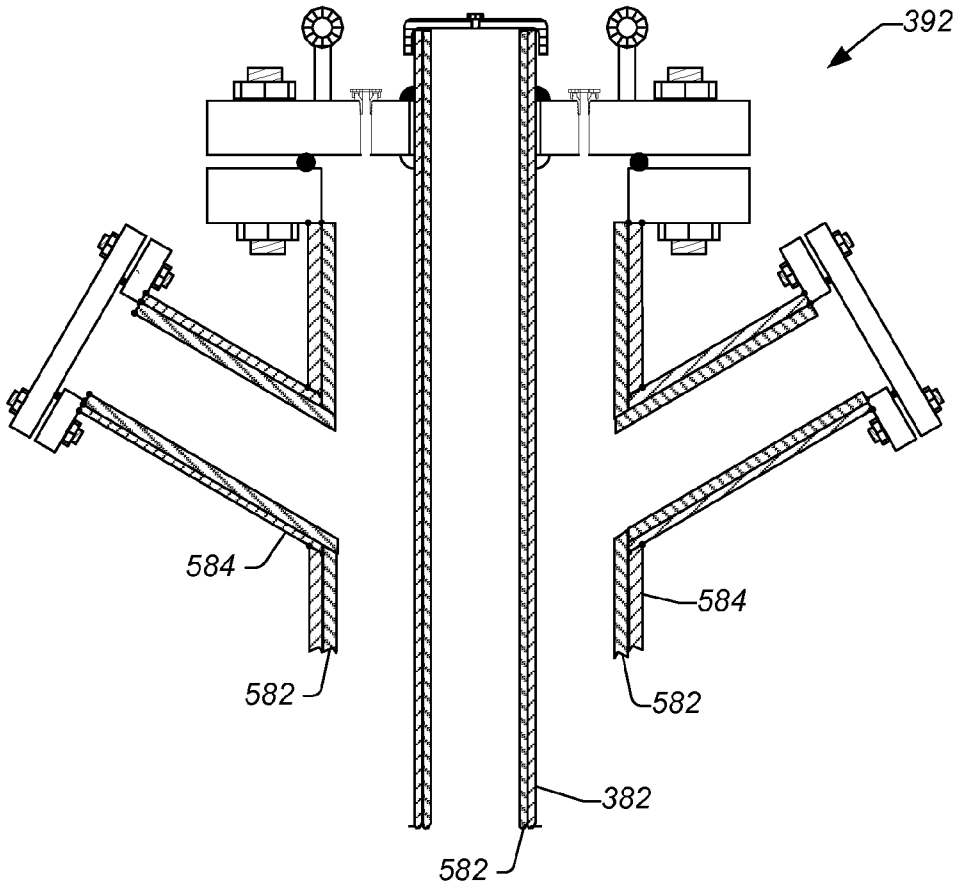


FIG. 109

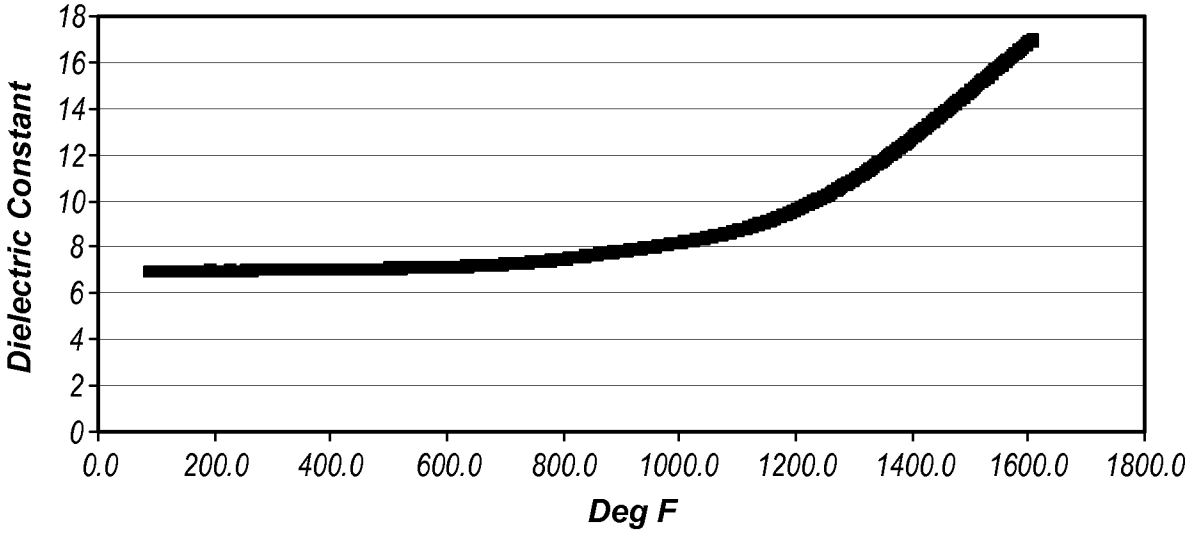


FIG. 110

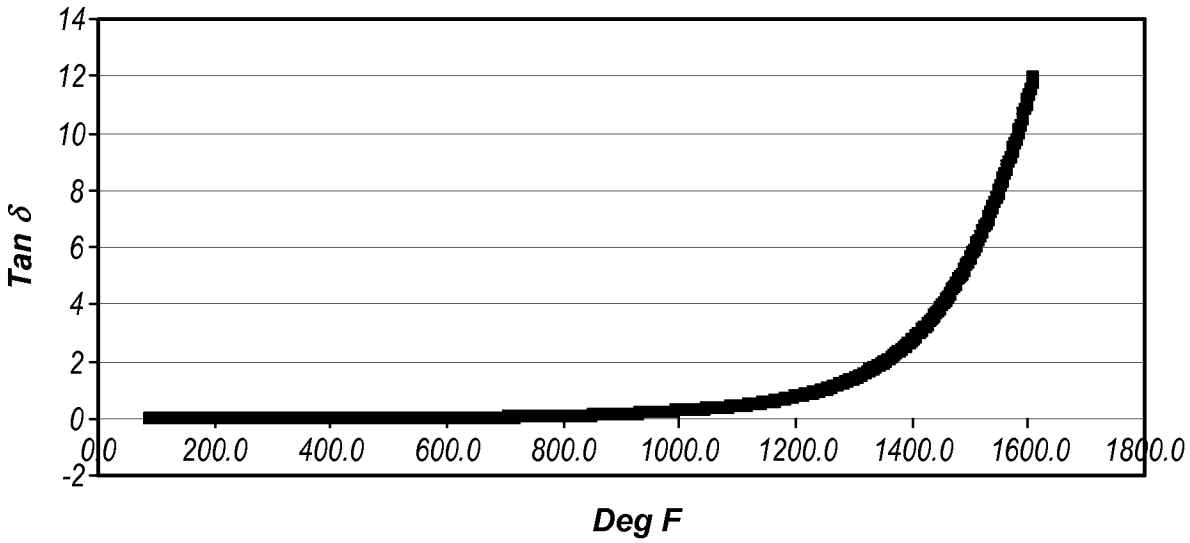


FIG. 111

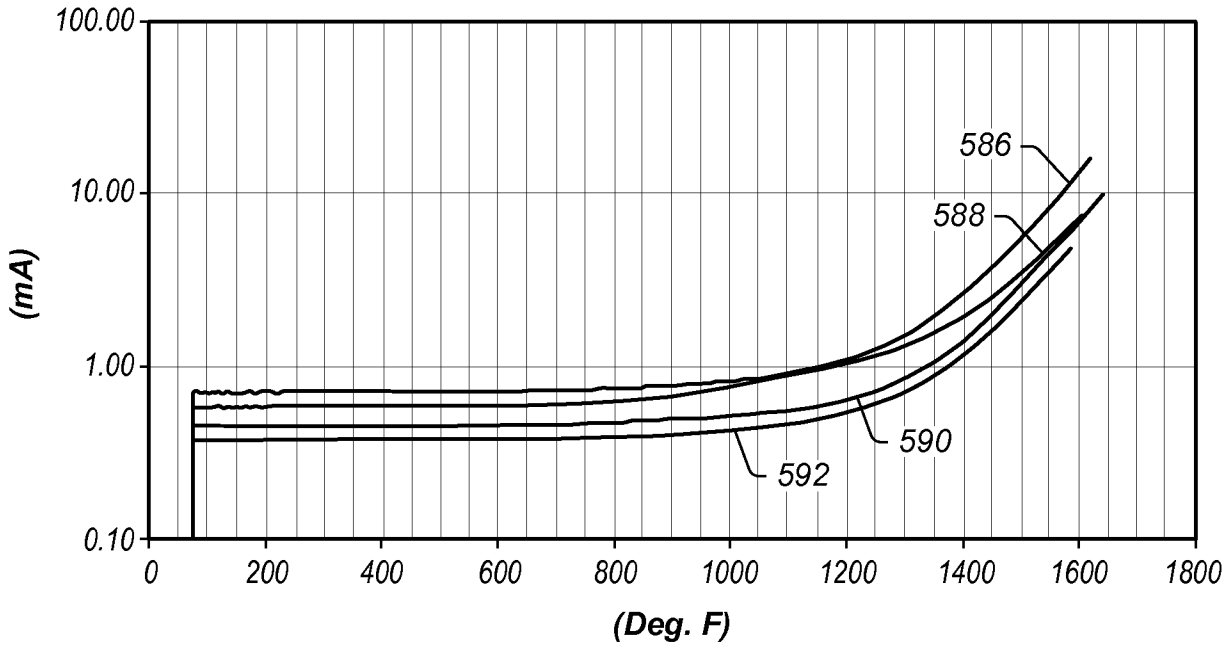


FIG. 112

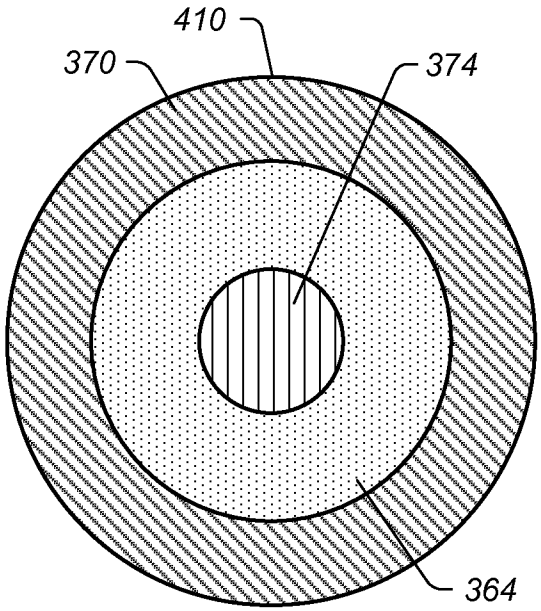


FIG. 113

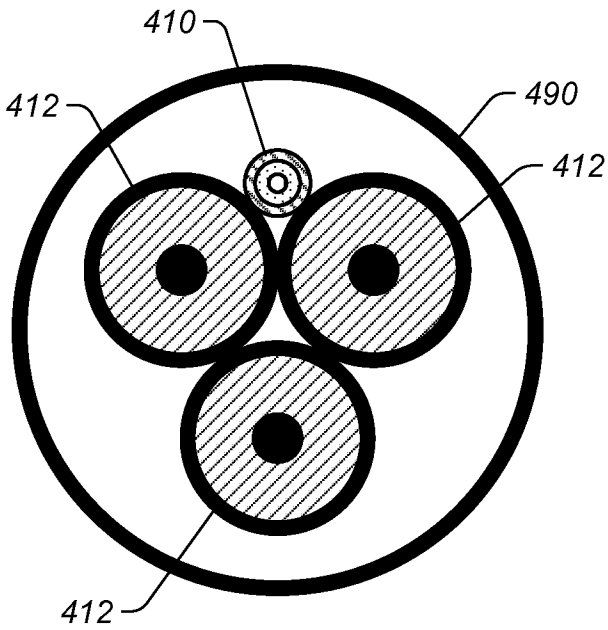


FIG. 114

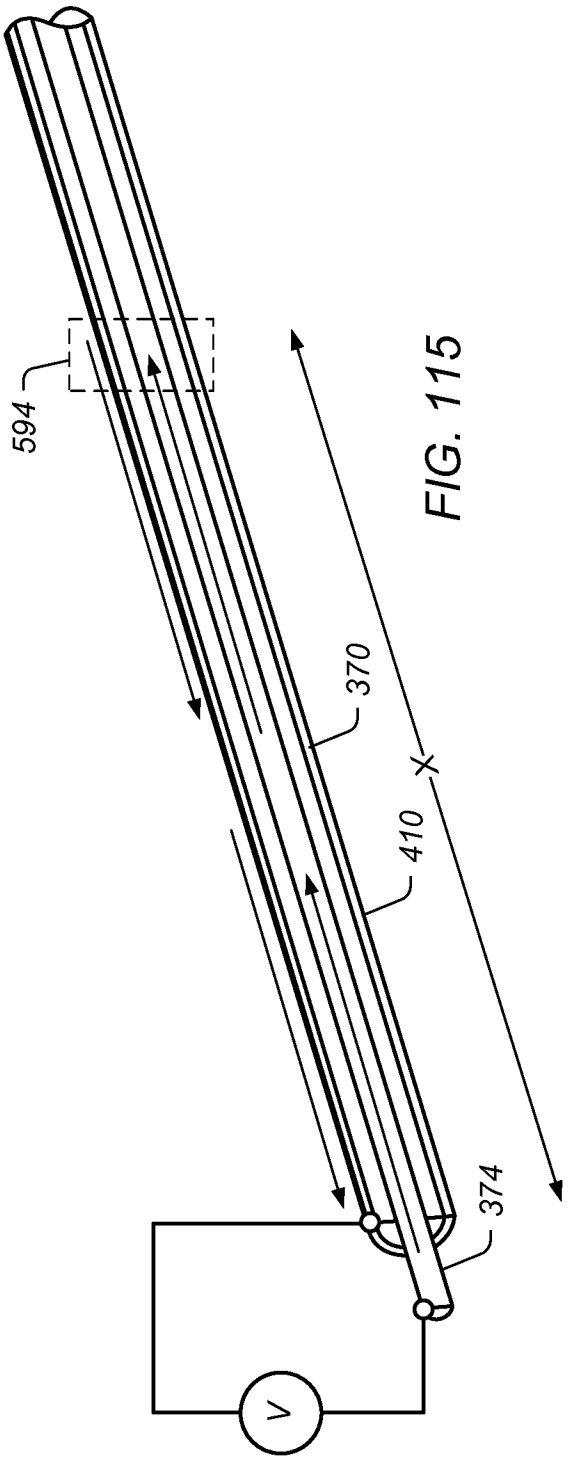


FIG. 115

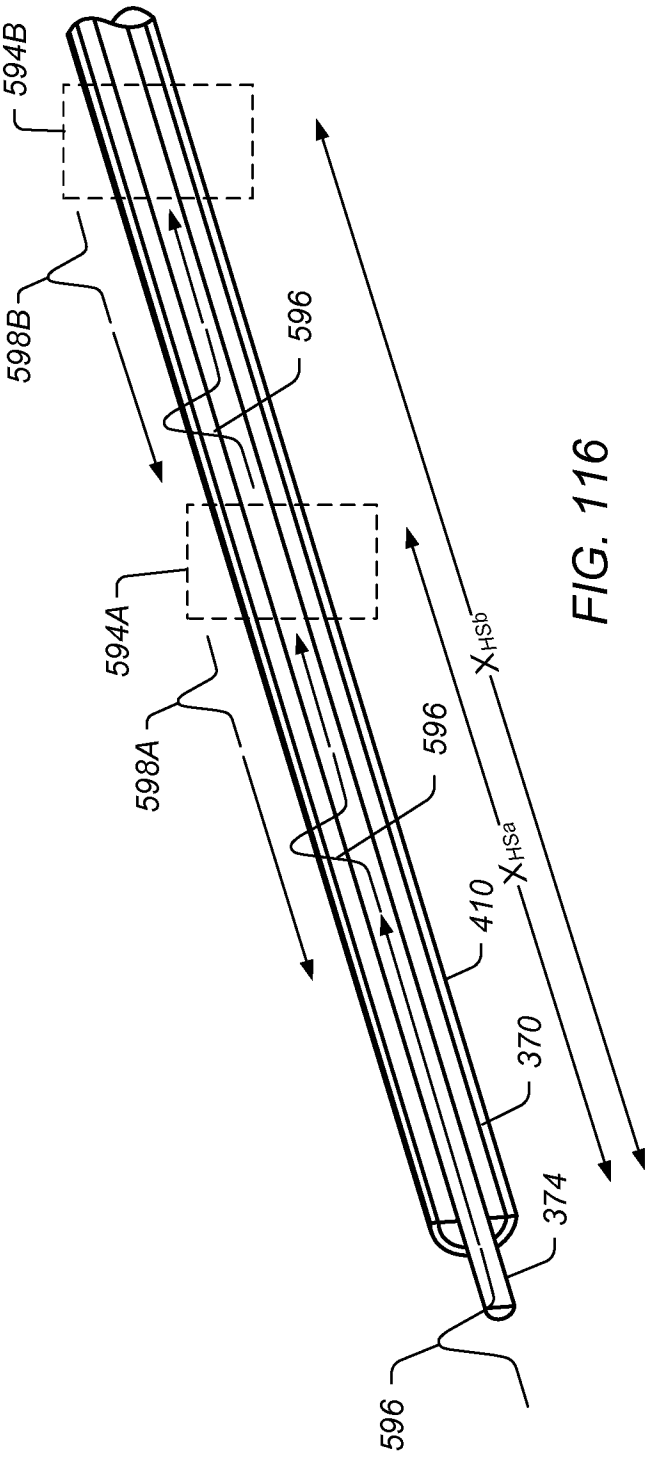


FIG. 116

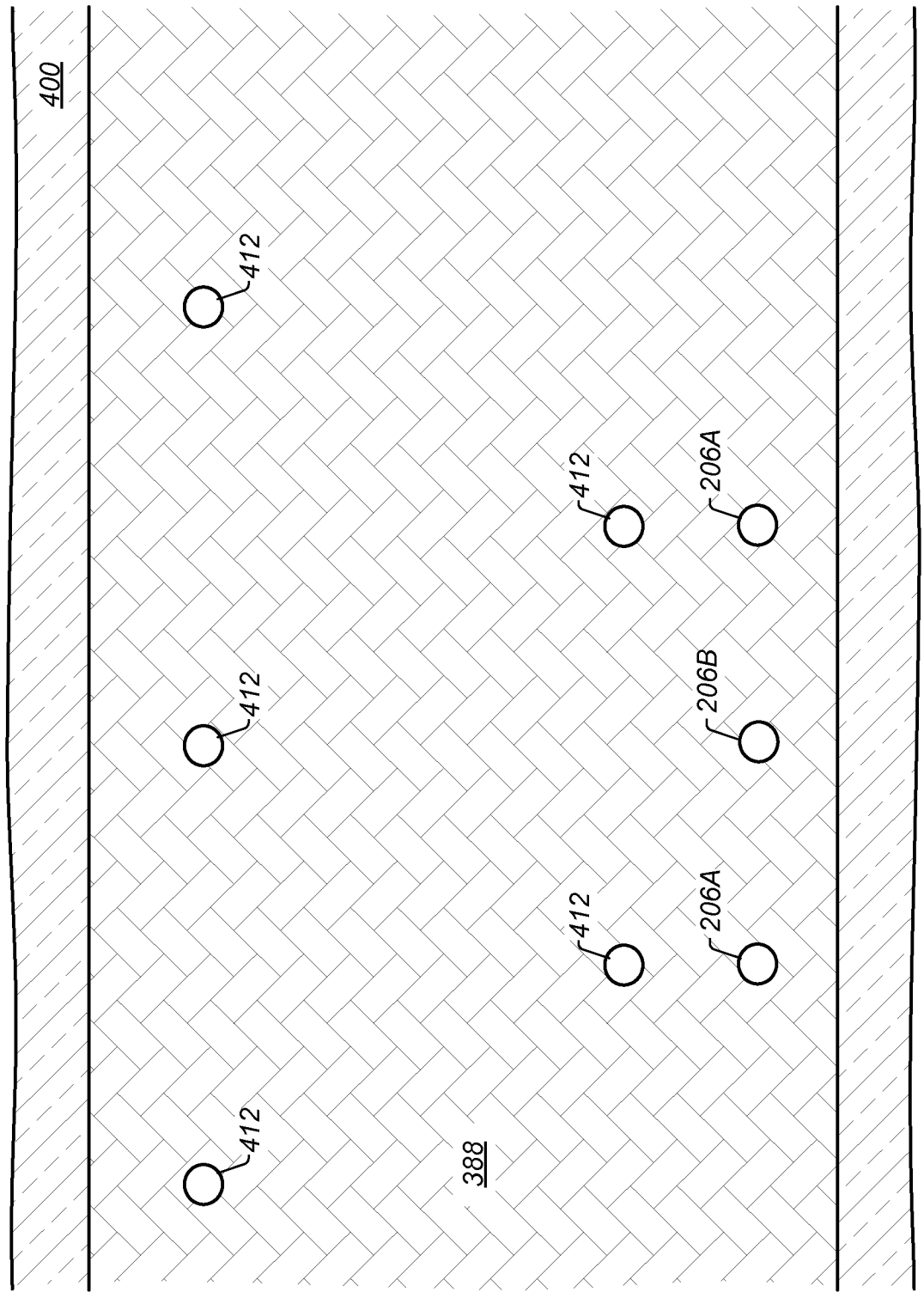


FIG. 117

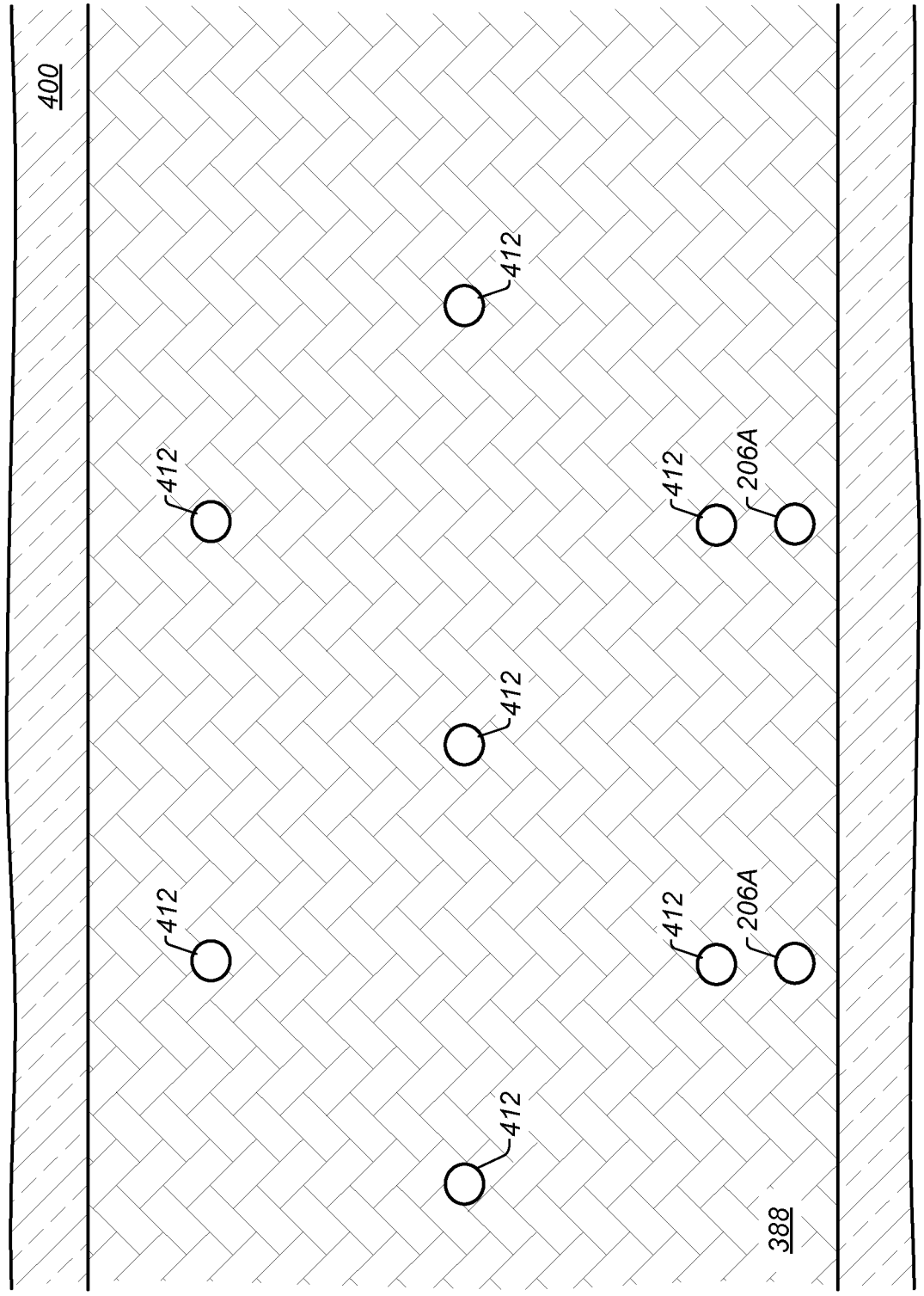


FIG. 118

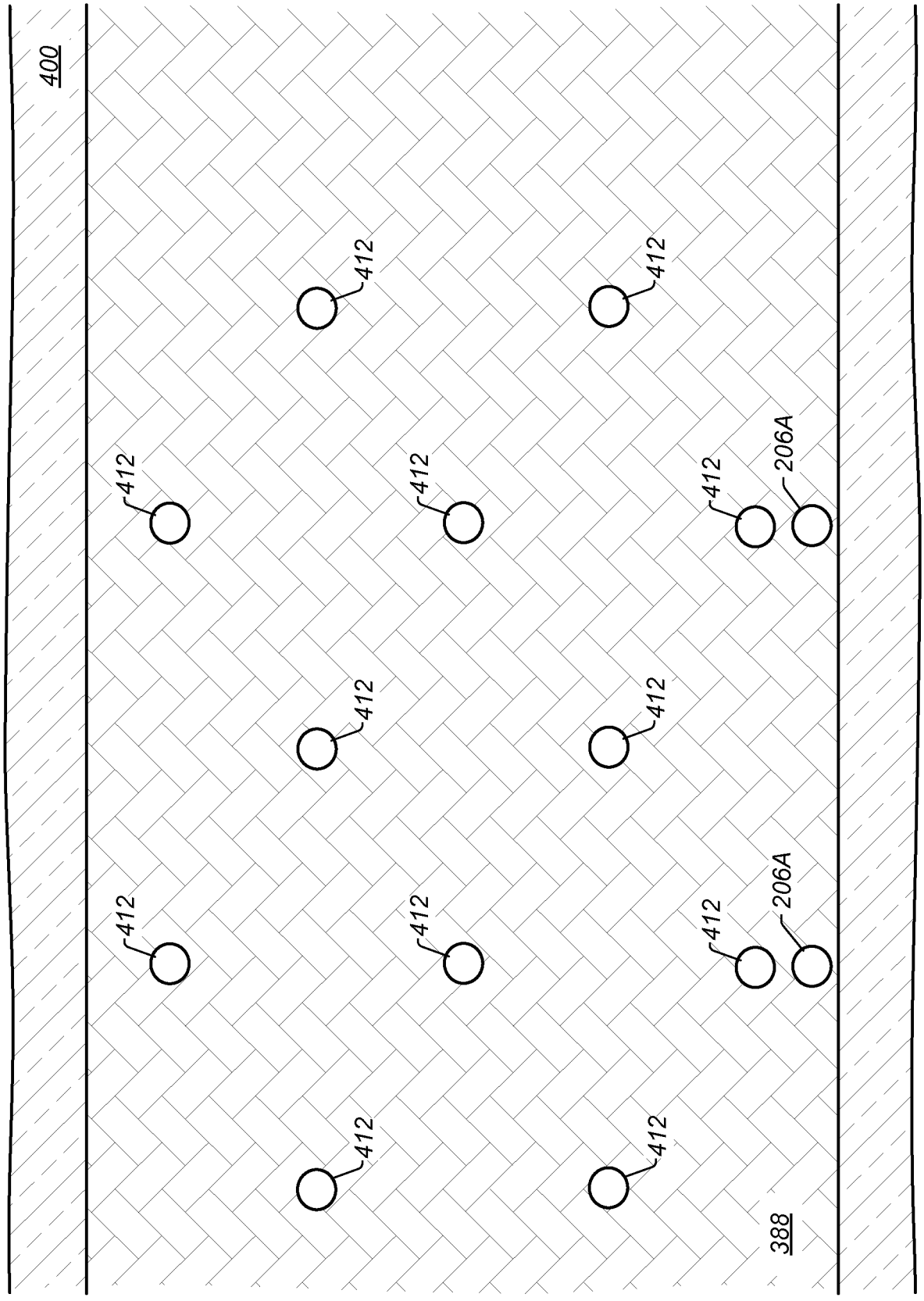

400
412
412
412
412
412
412
412
412
412
412
412
412
206A
206A
388

FIG. 119

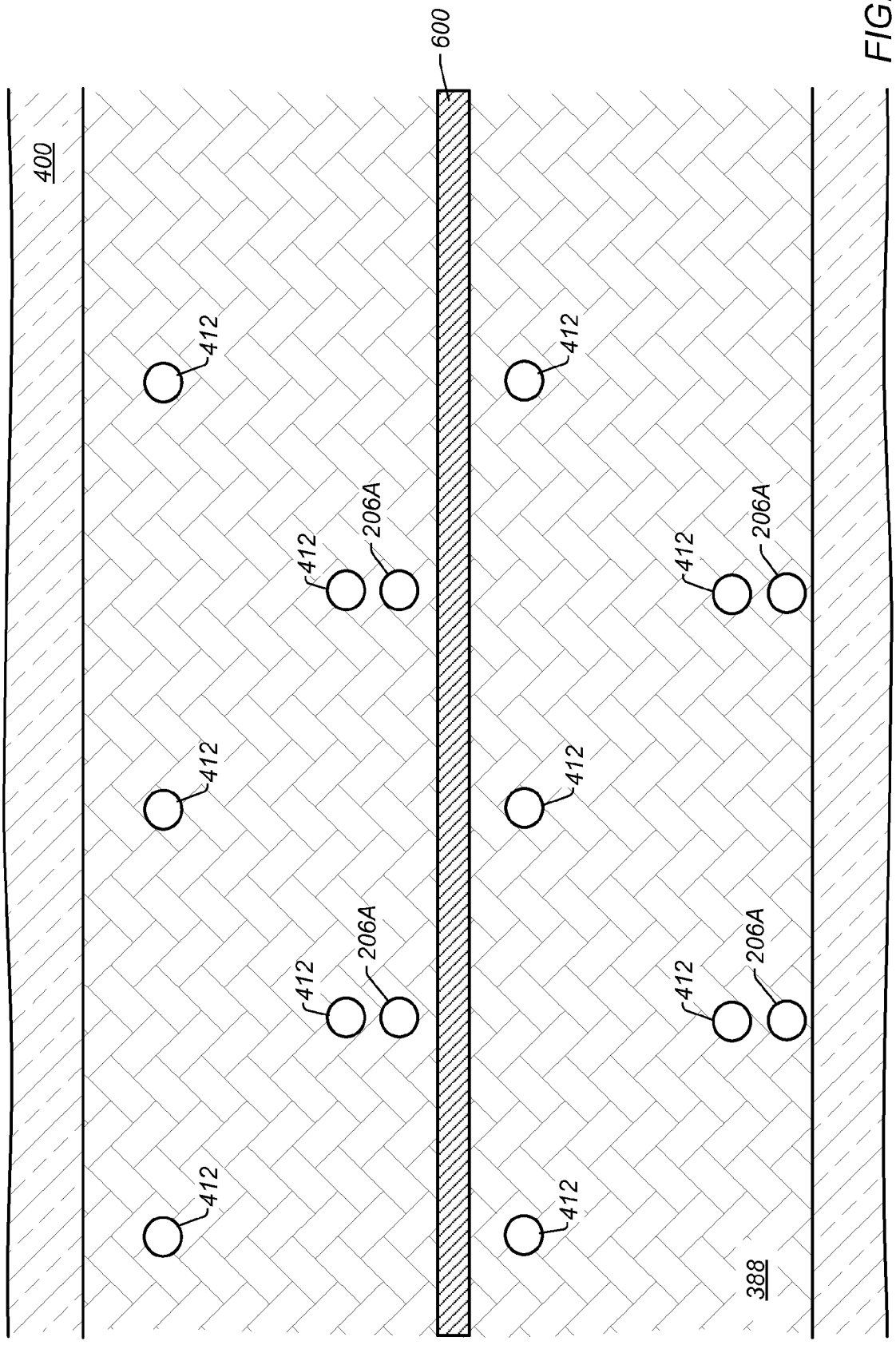

600
400
412
412
206A
412
206A
412
412
206A
412
206A
412
412
412
388

FIG. 120

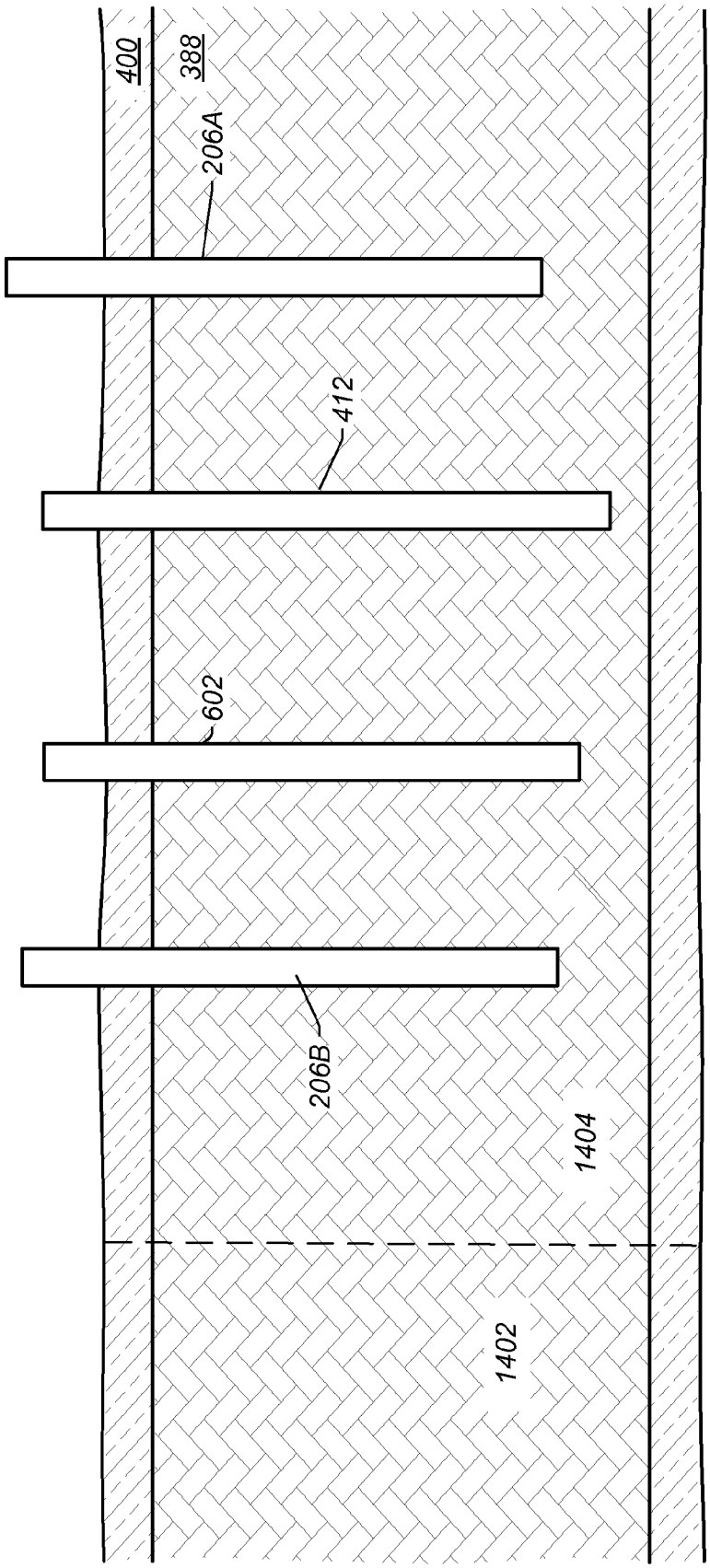


FIG. 121

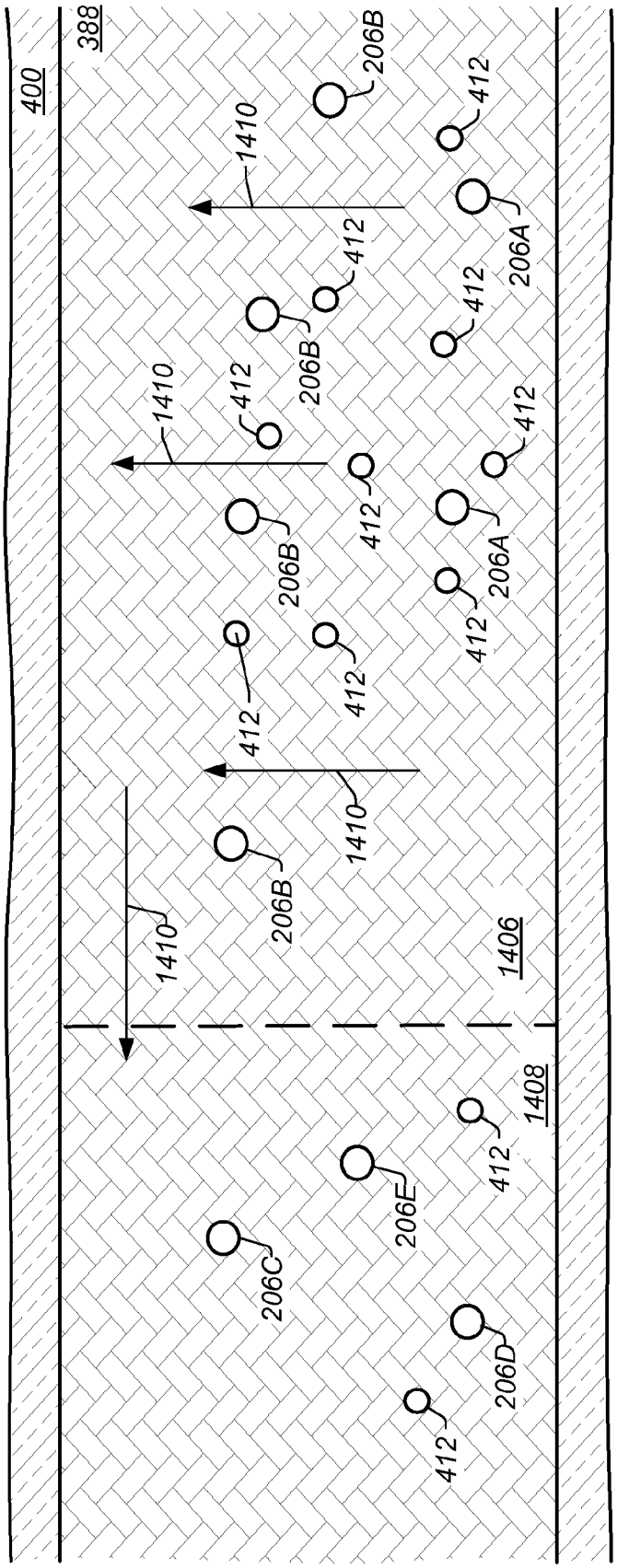
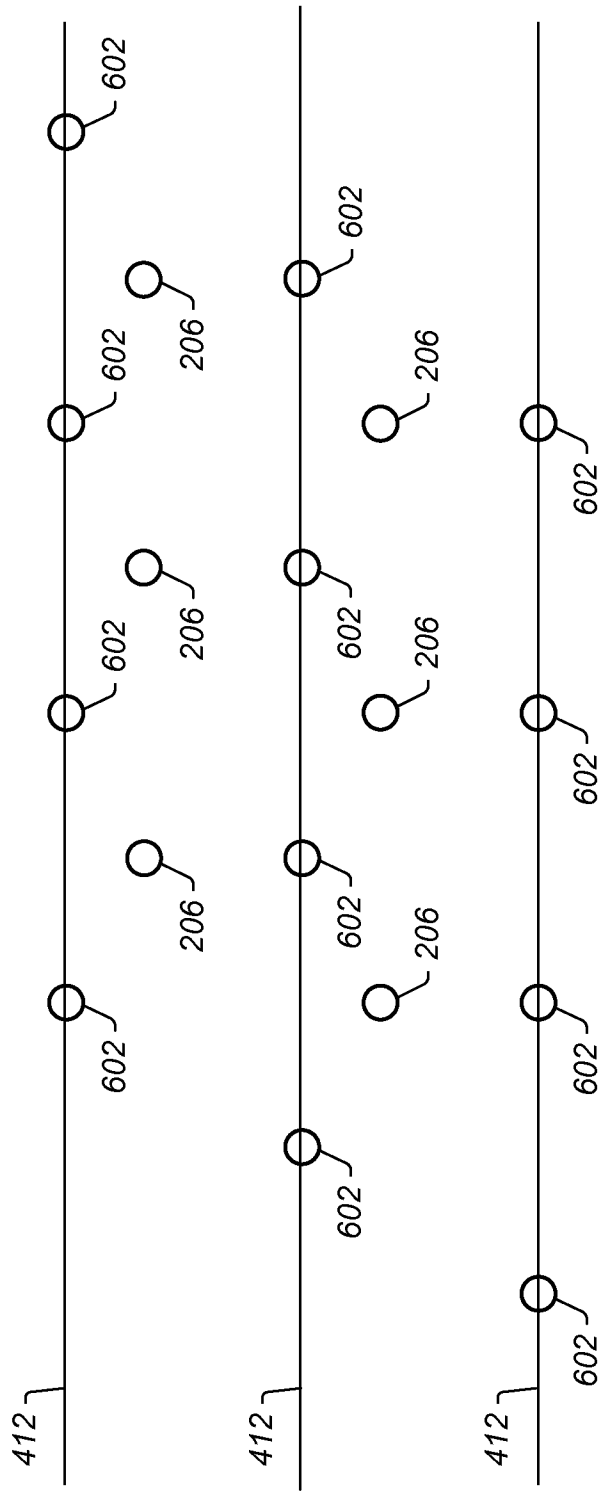


FIG. 122


412
602
206
602
206
602
206

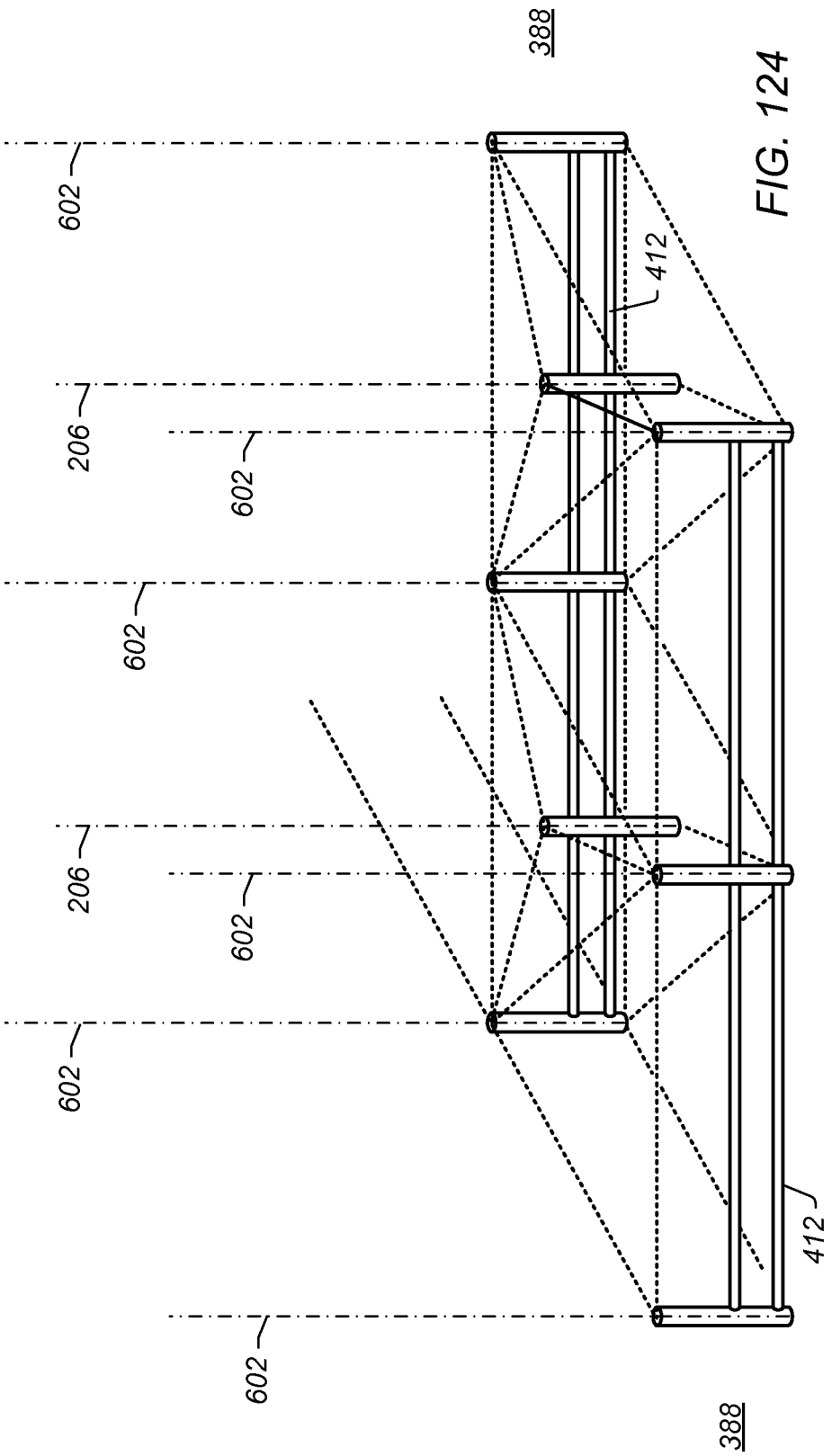
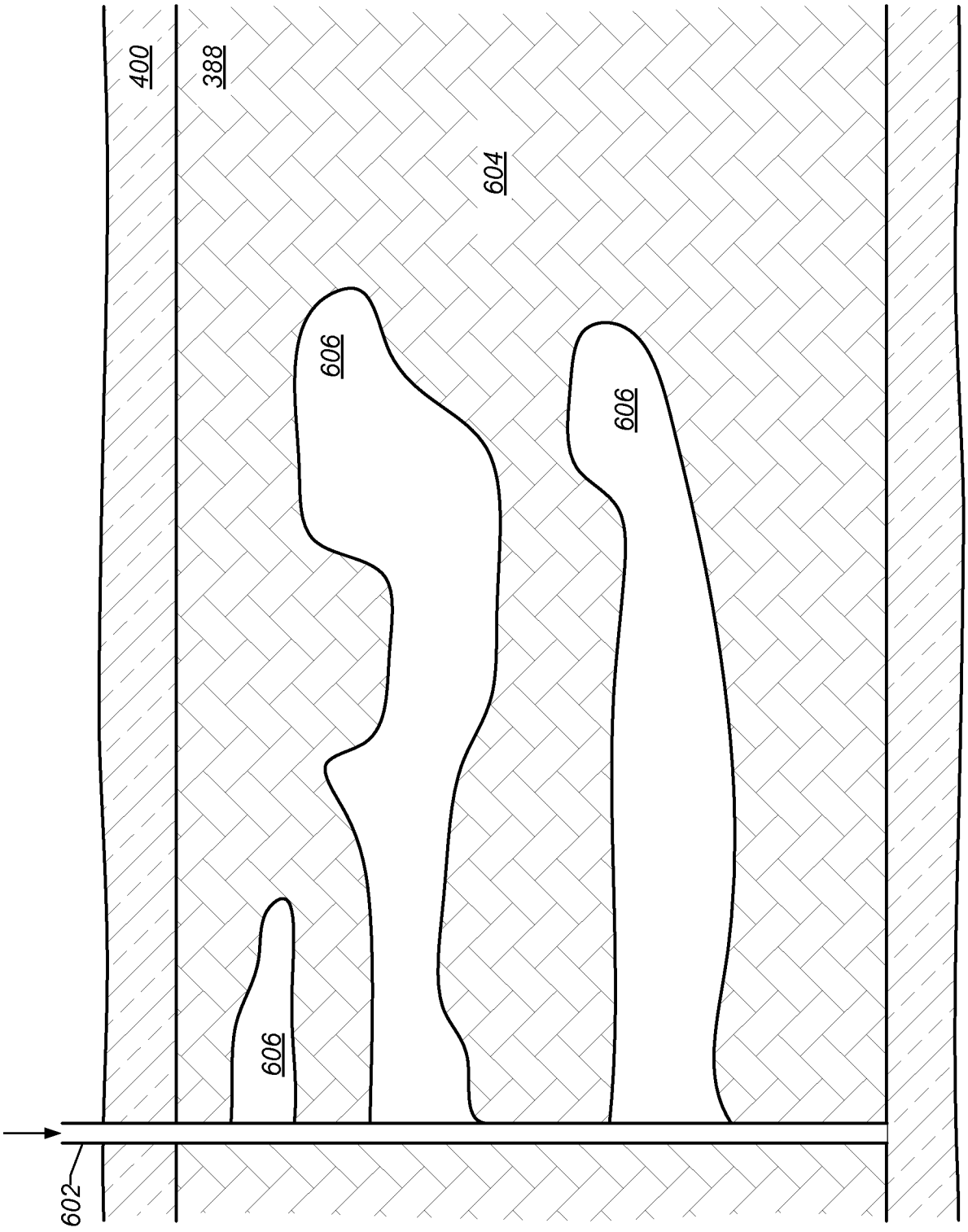


FIG. 124

FIG. 125



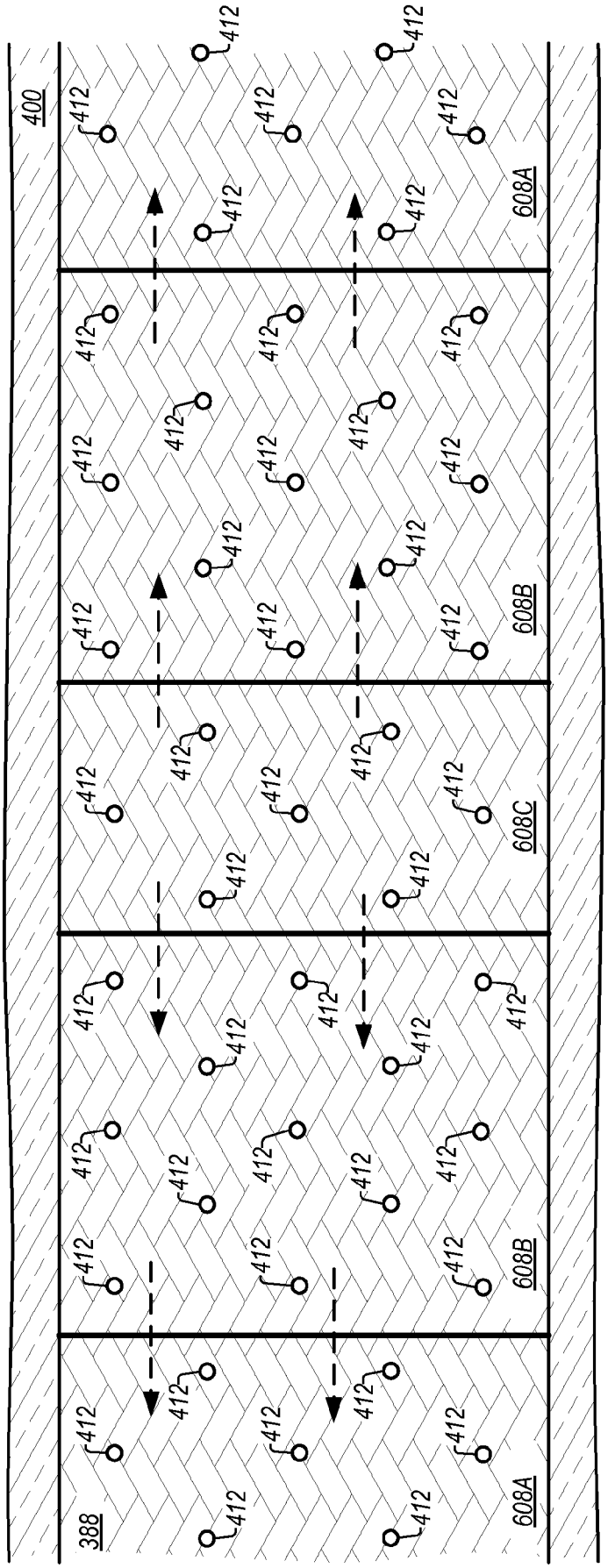


FIG. 126

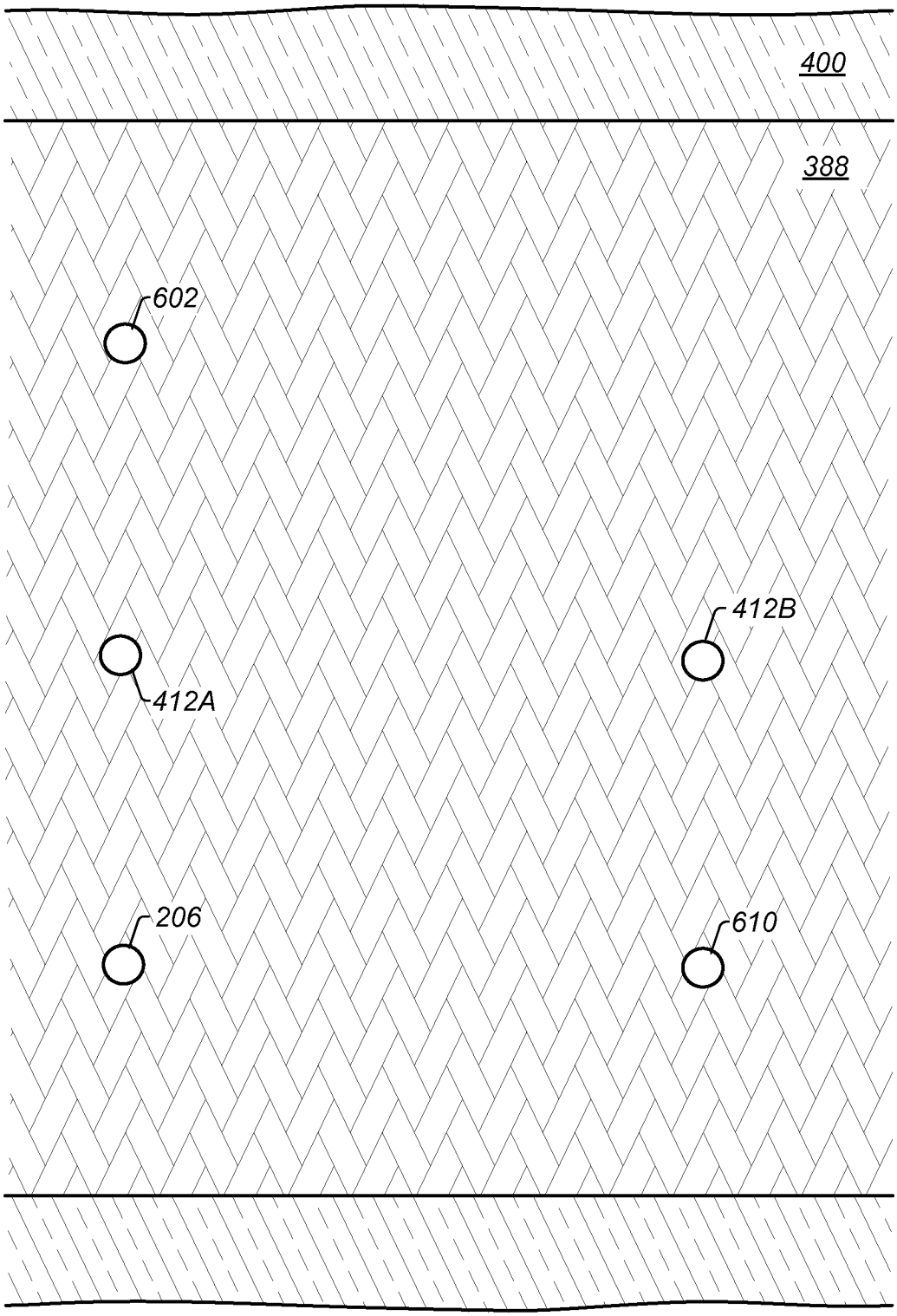


FIG. 127

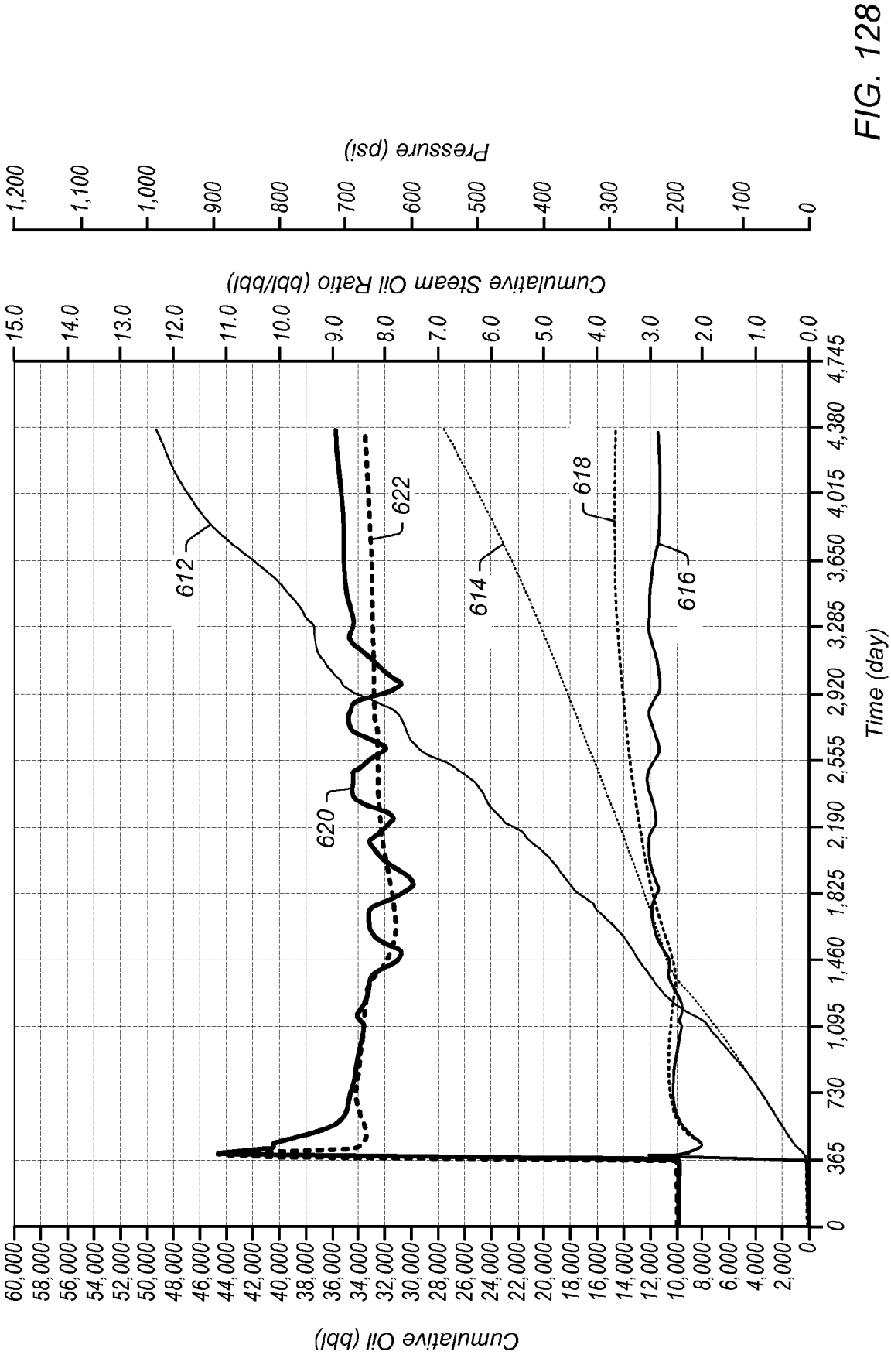

Cumulative Oil (bbl)
60,000
58,000
56,000
54,000
52,000
50,000
48,000
46,000
44,000
42,000
40,000
38,000
36,000
34,000
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Time (day)
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
Cumulative Steam Oil Ratio (bbl/bbl)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Pressure (psi)
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
612
622
620
614
618
616

FIG. 128

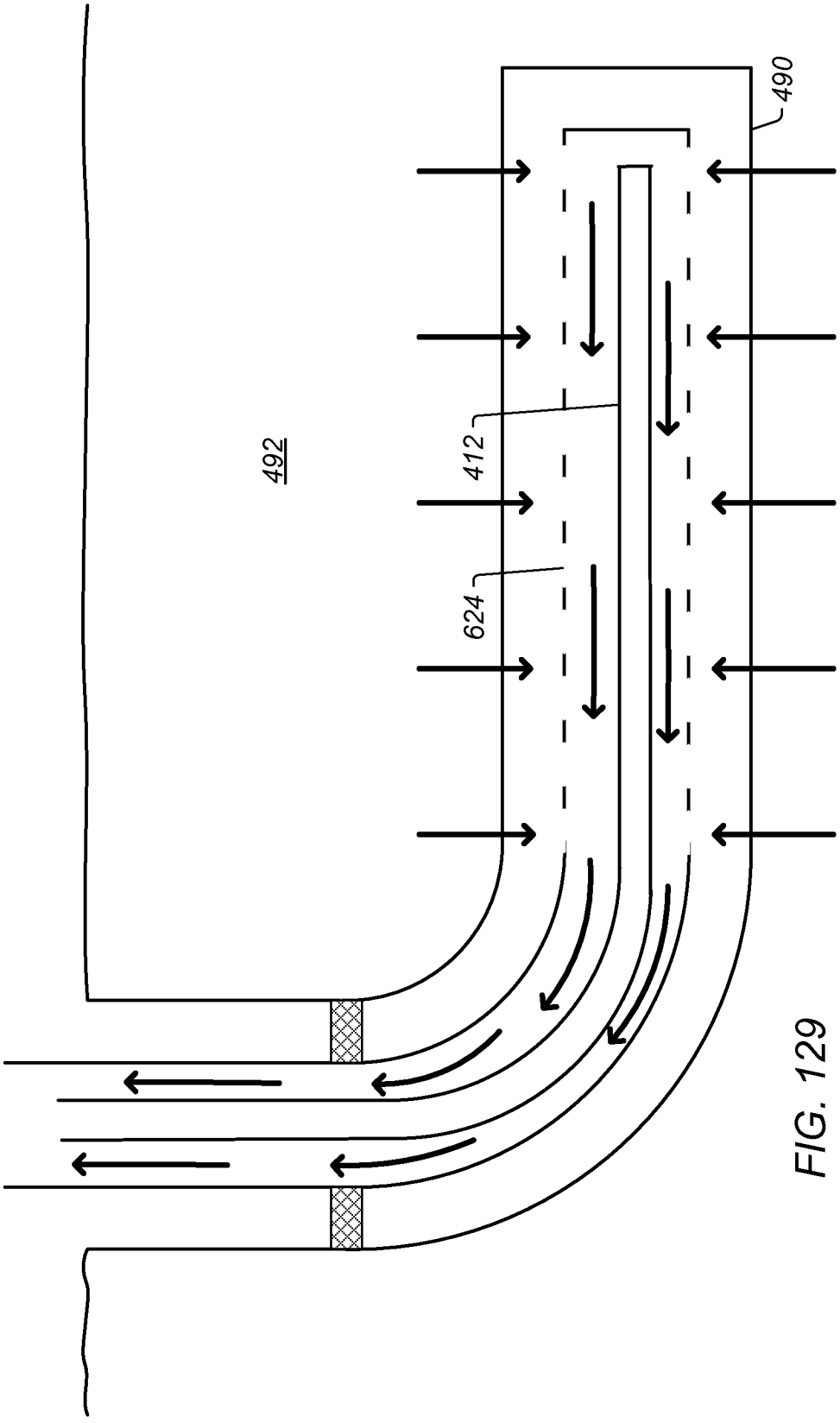


FIG. 129

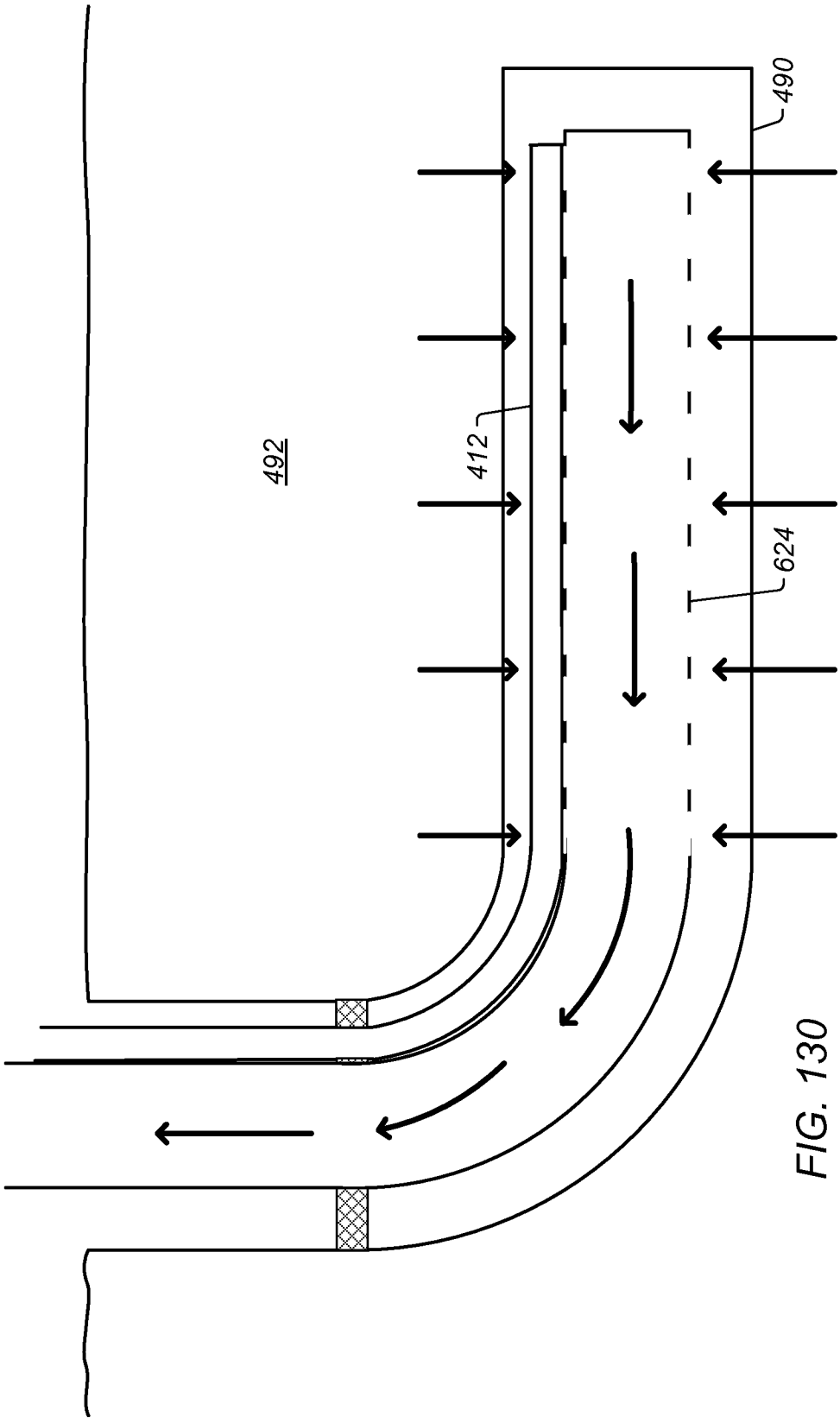


FIG. 130

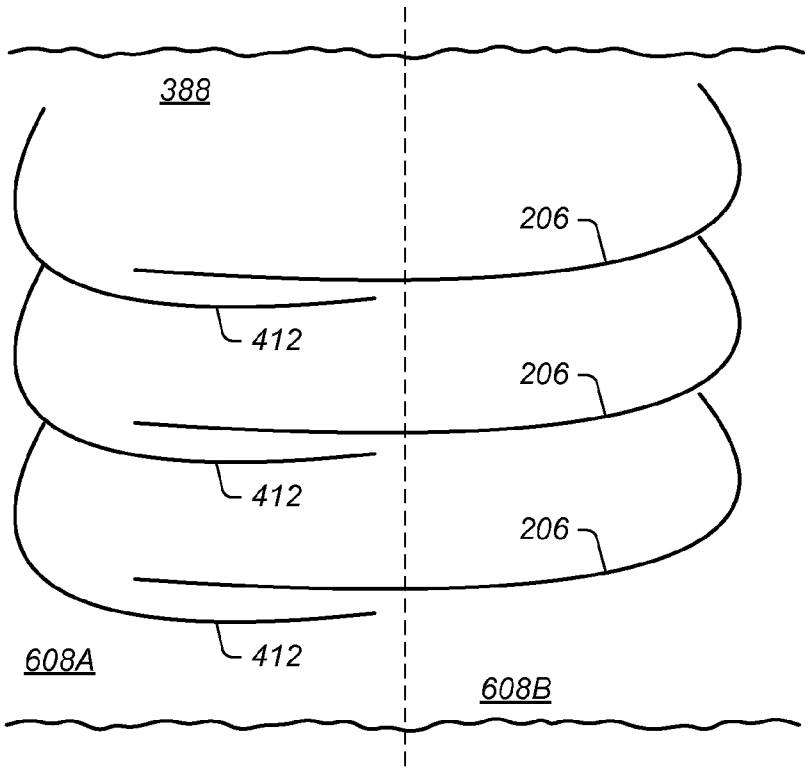


FIG. 131

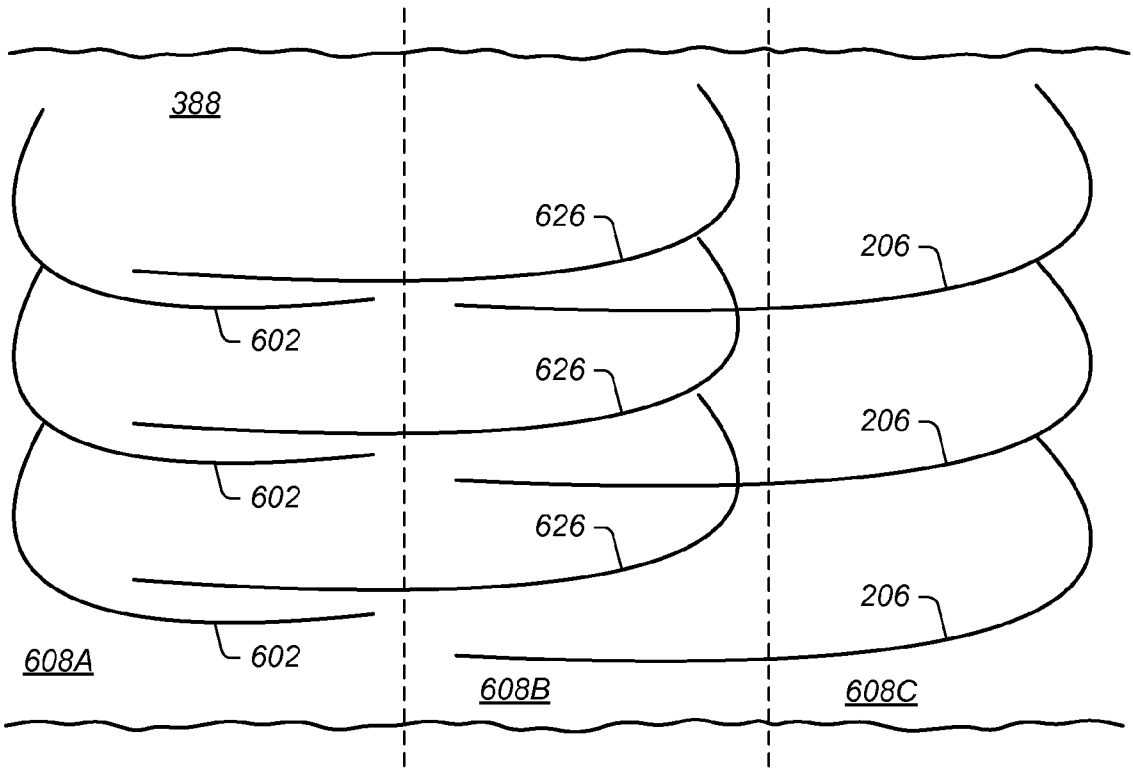


FIG. 132

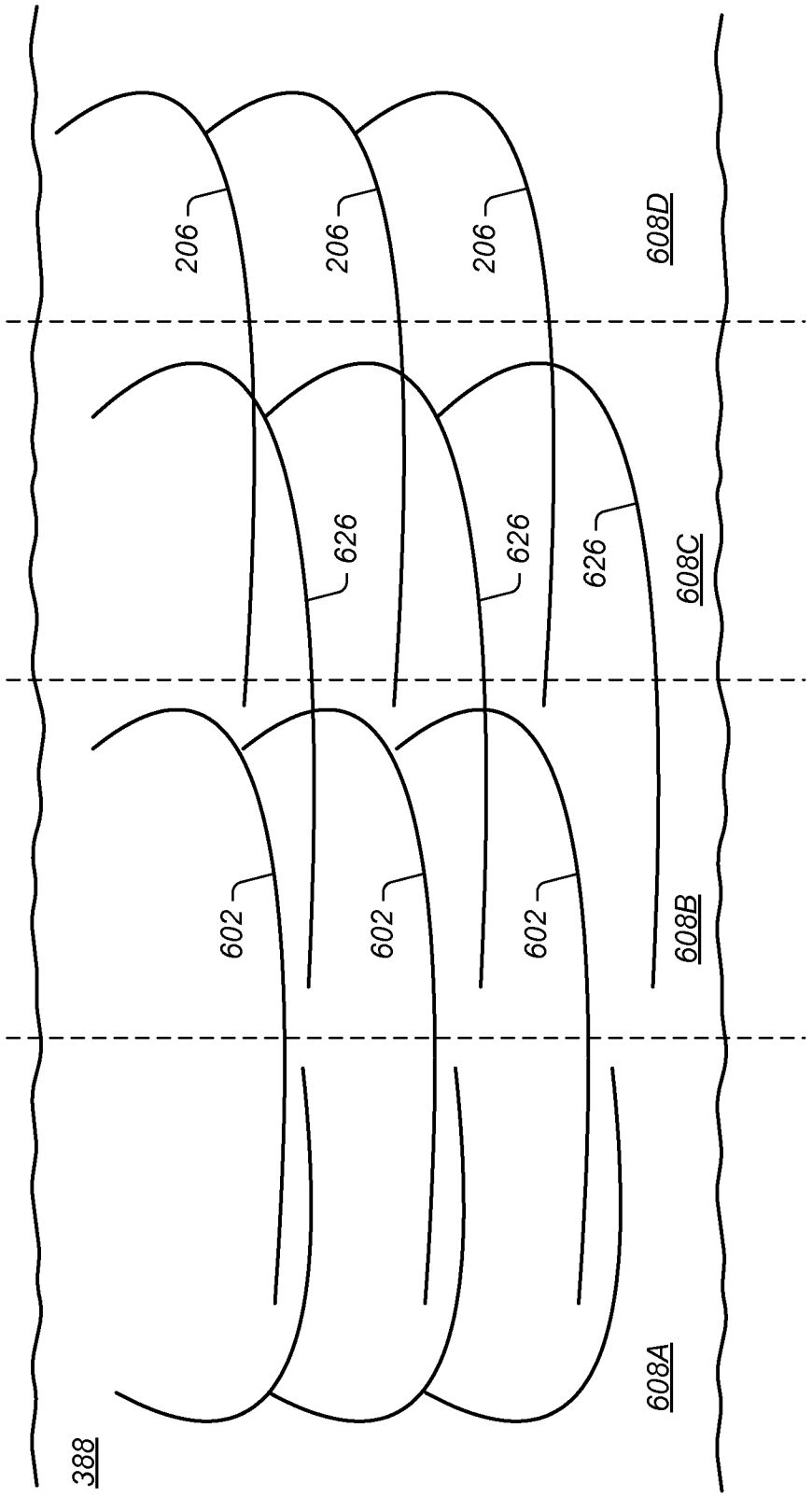


FIG. 133

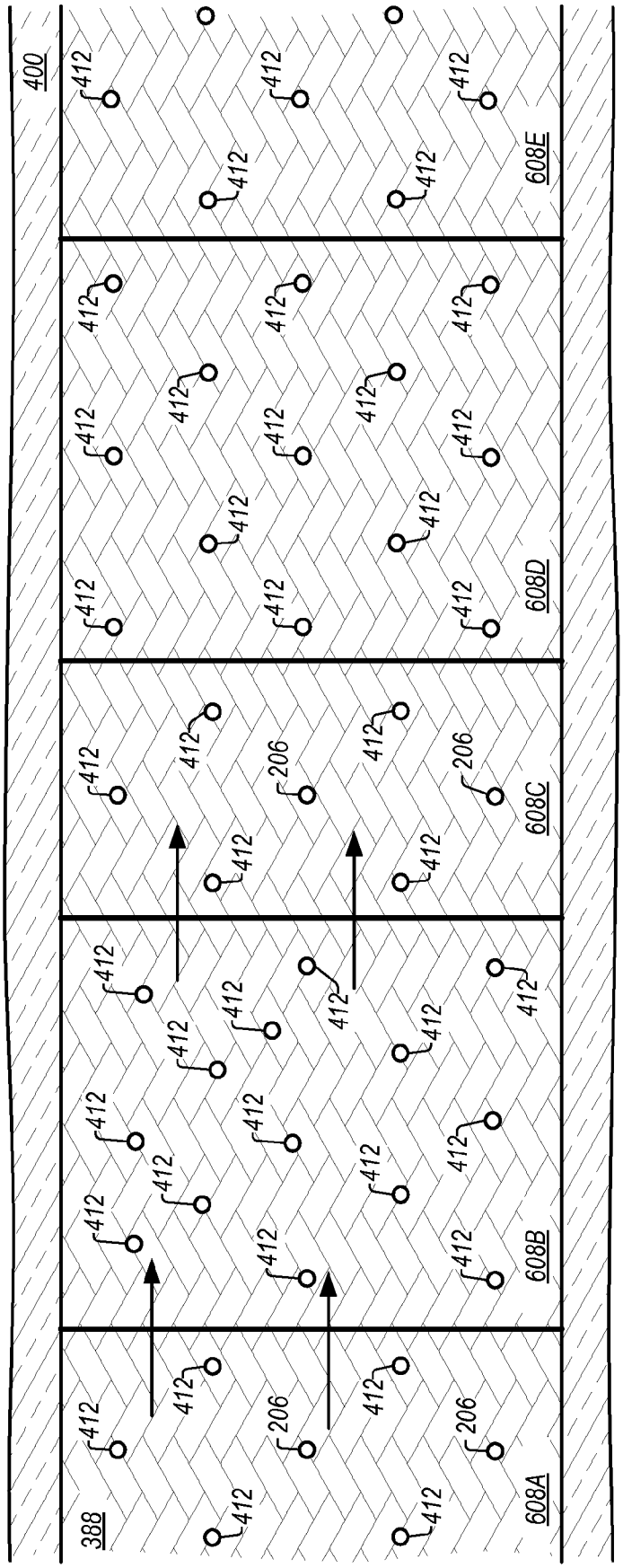


FIG. 134

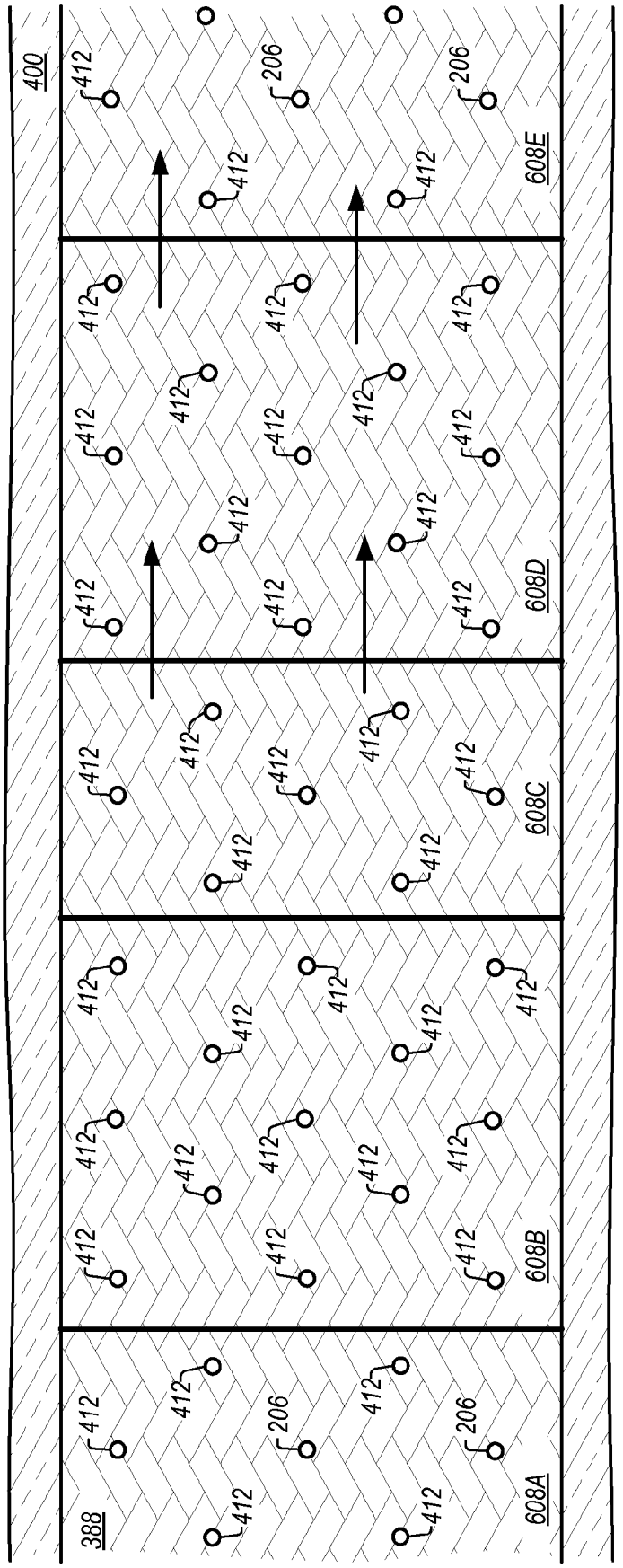


FIG. 135

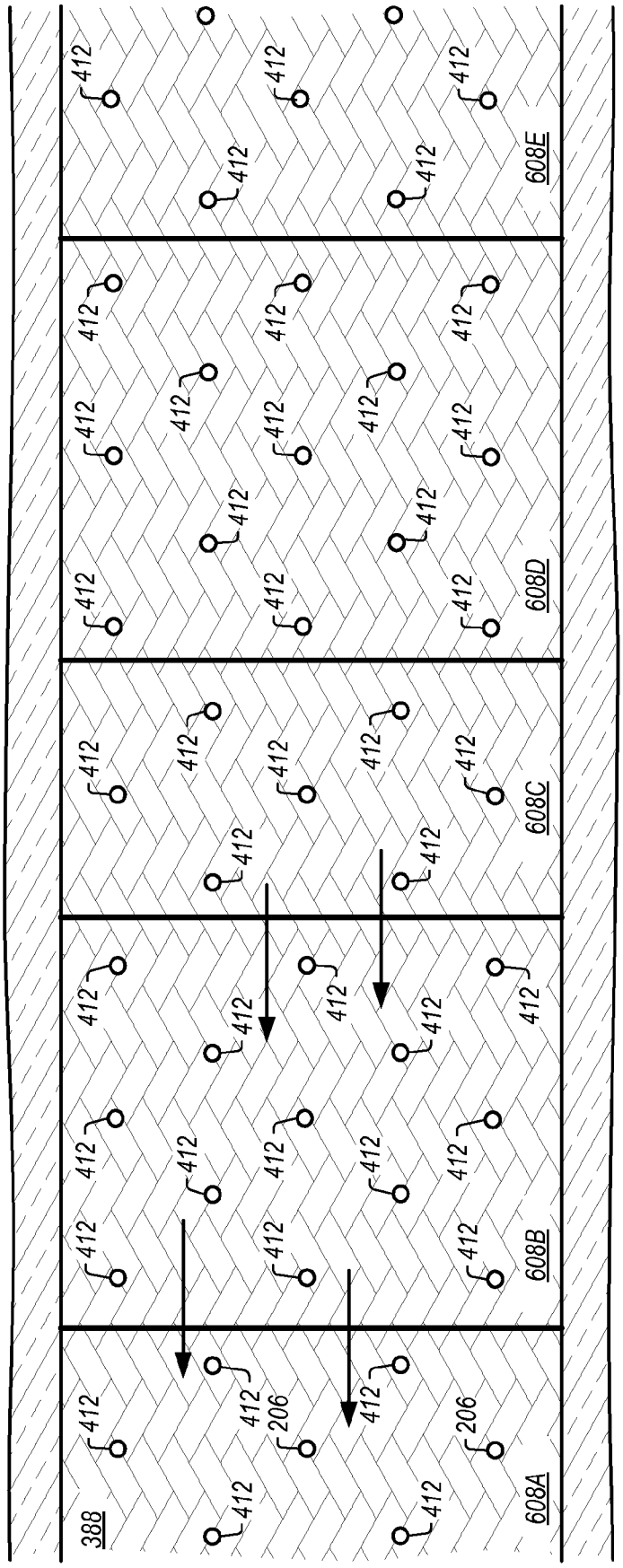


FIG. 136

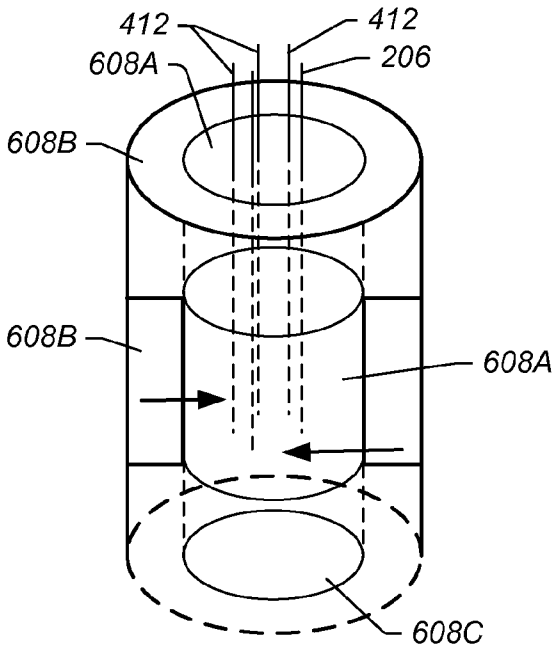


FIG. 137

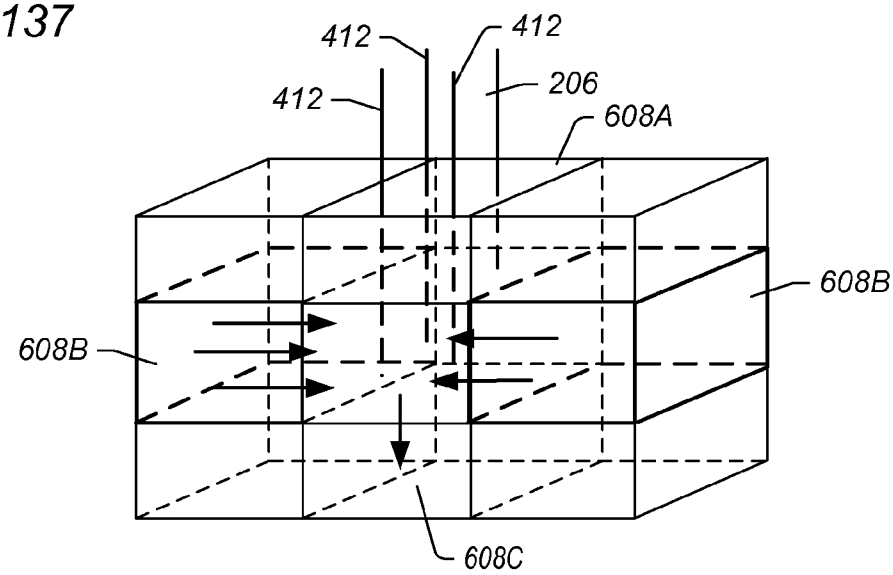


FIG. 138

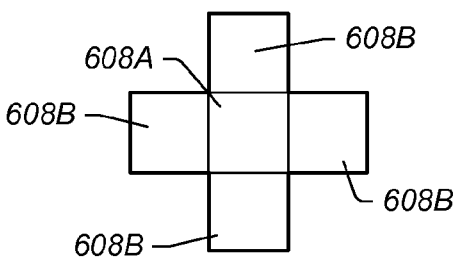


FIG. 139

FIG. 140

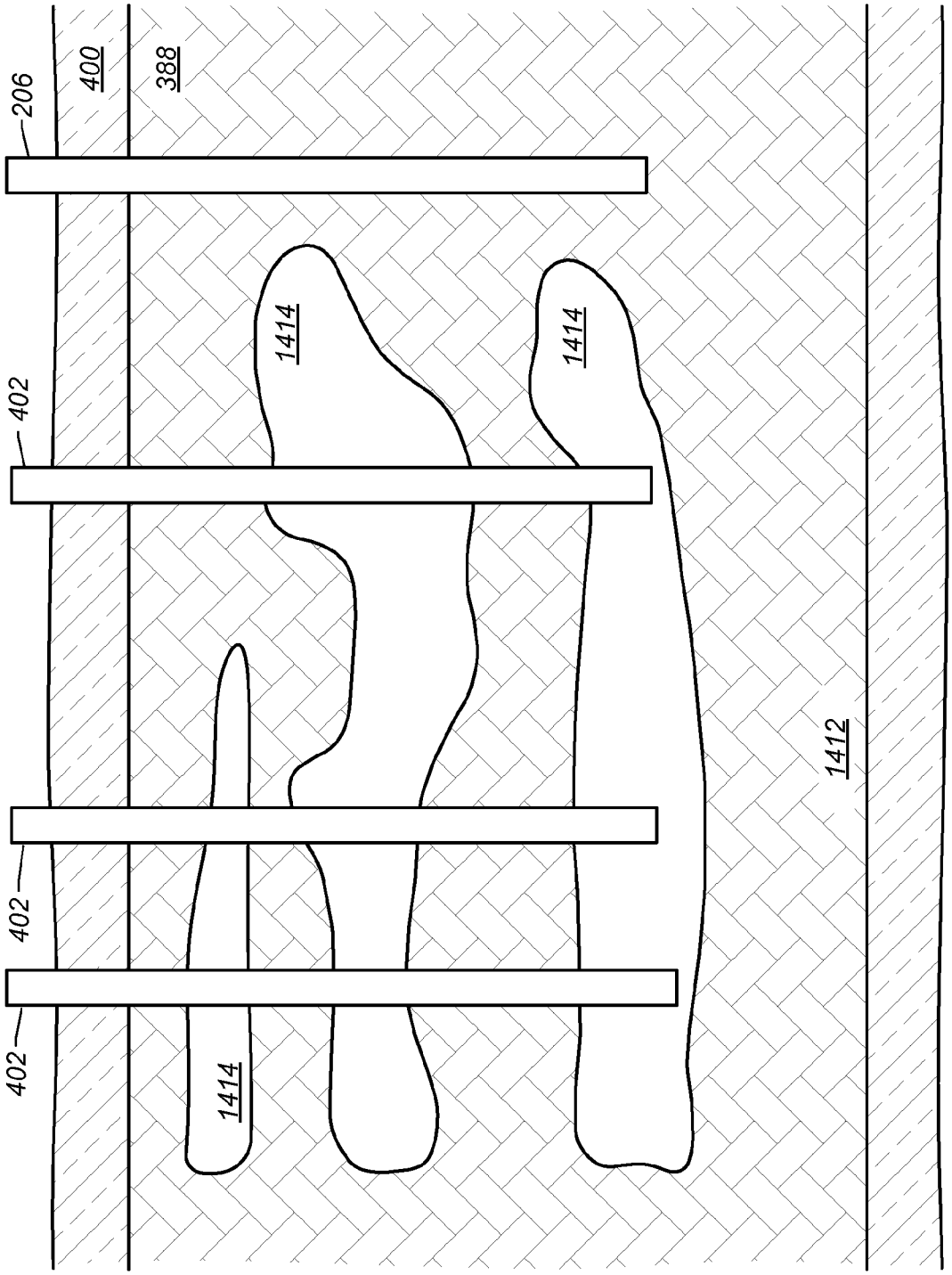
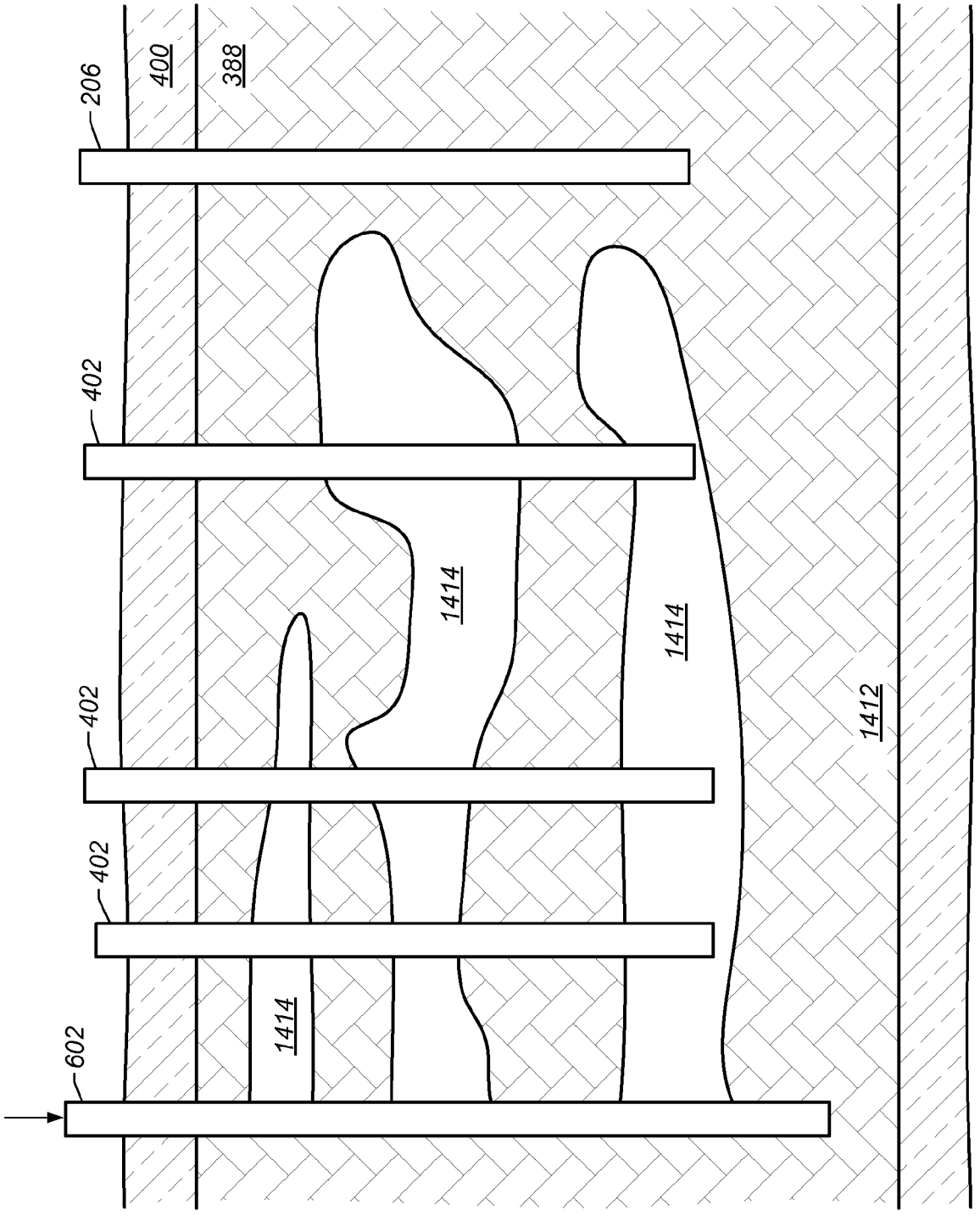


FIG. 141



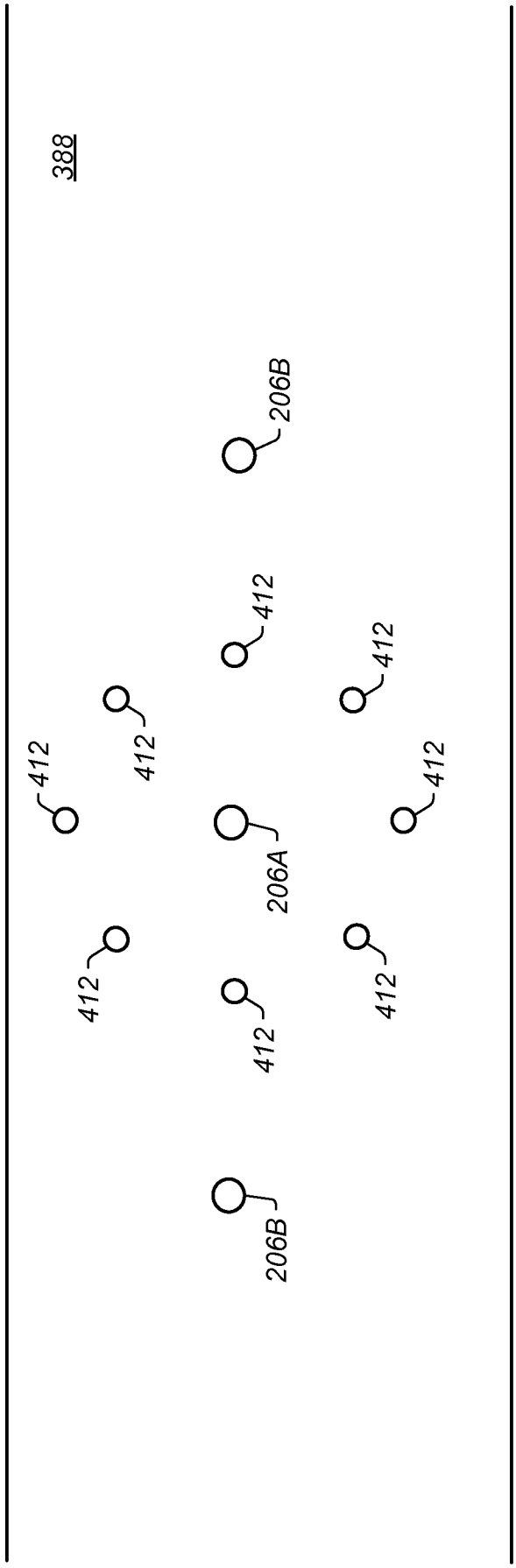


FIG. 142

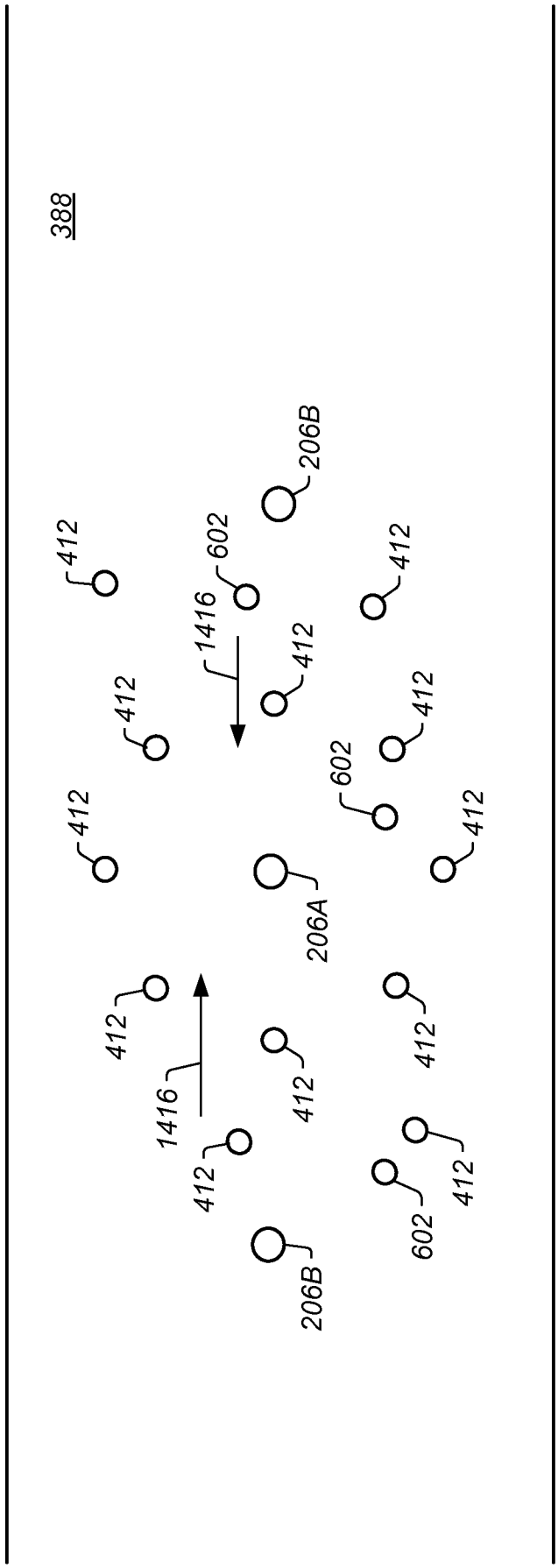

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FIG. 143

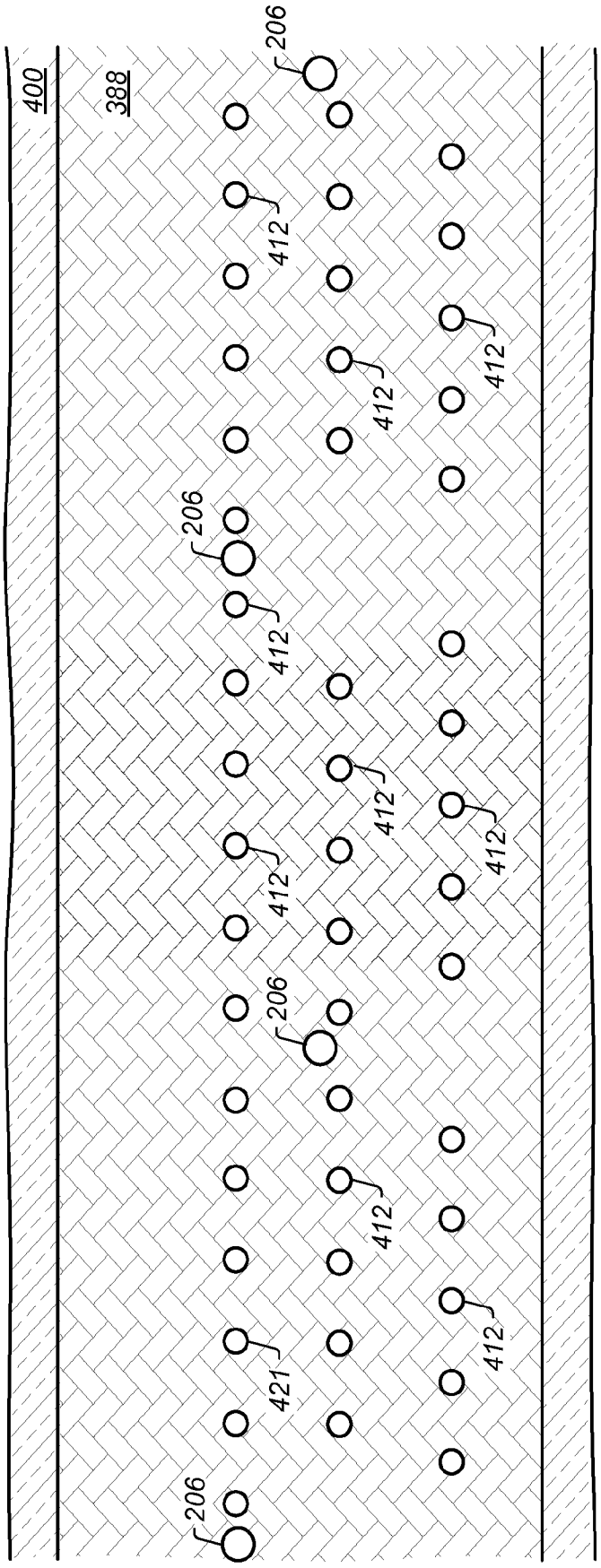


FIG. 144

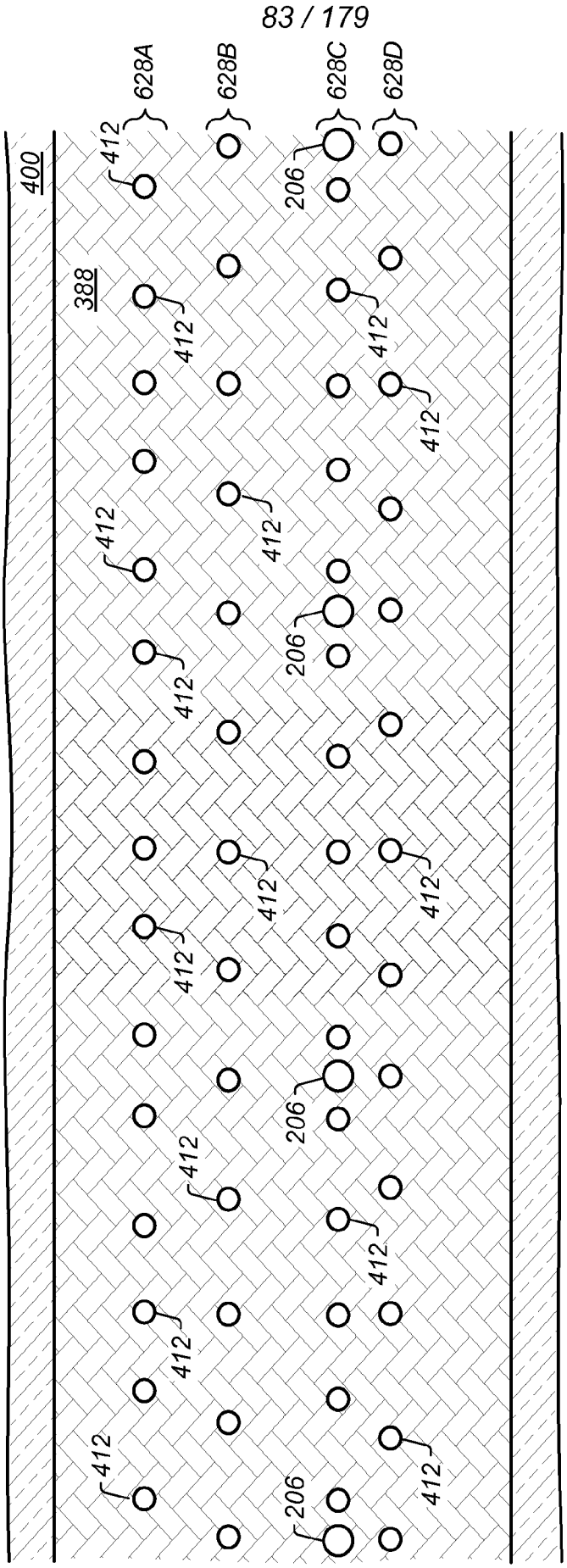


FIG. 145

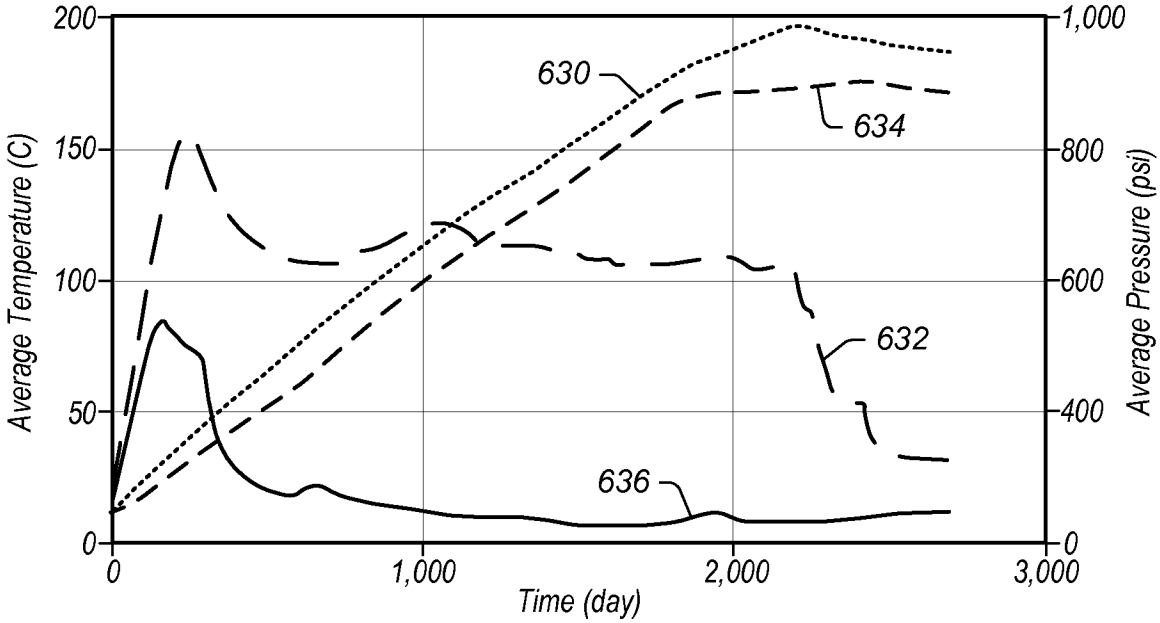


FIG. 146

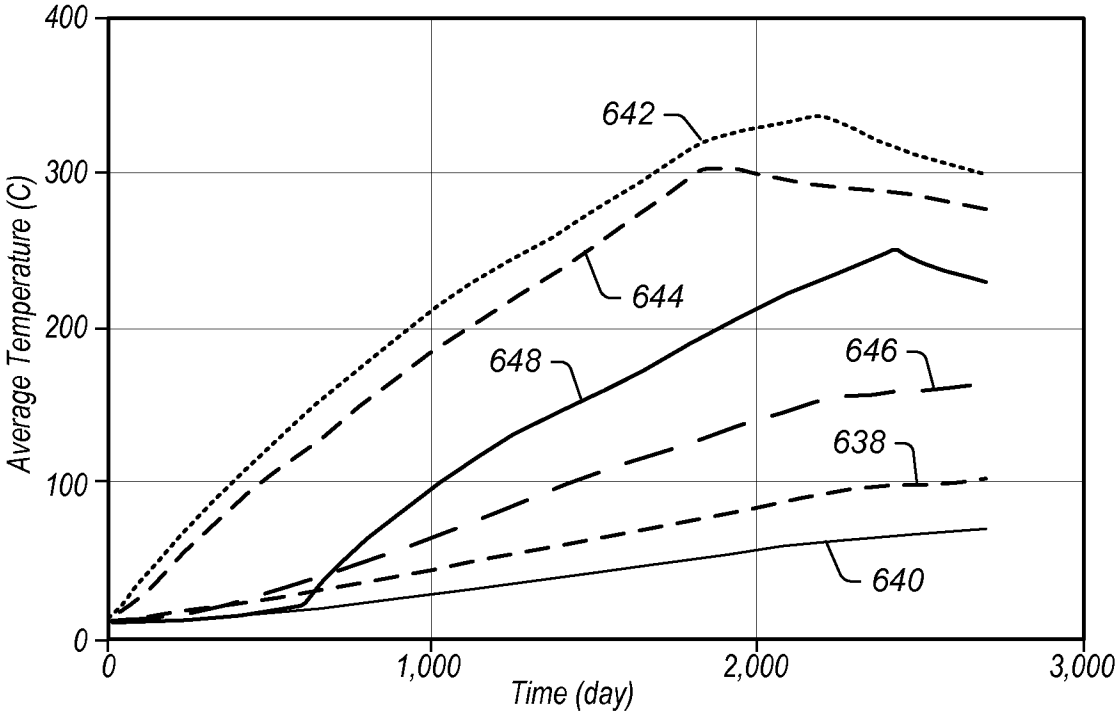


FIG. 147

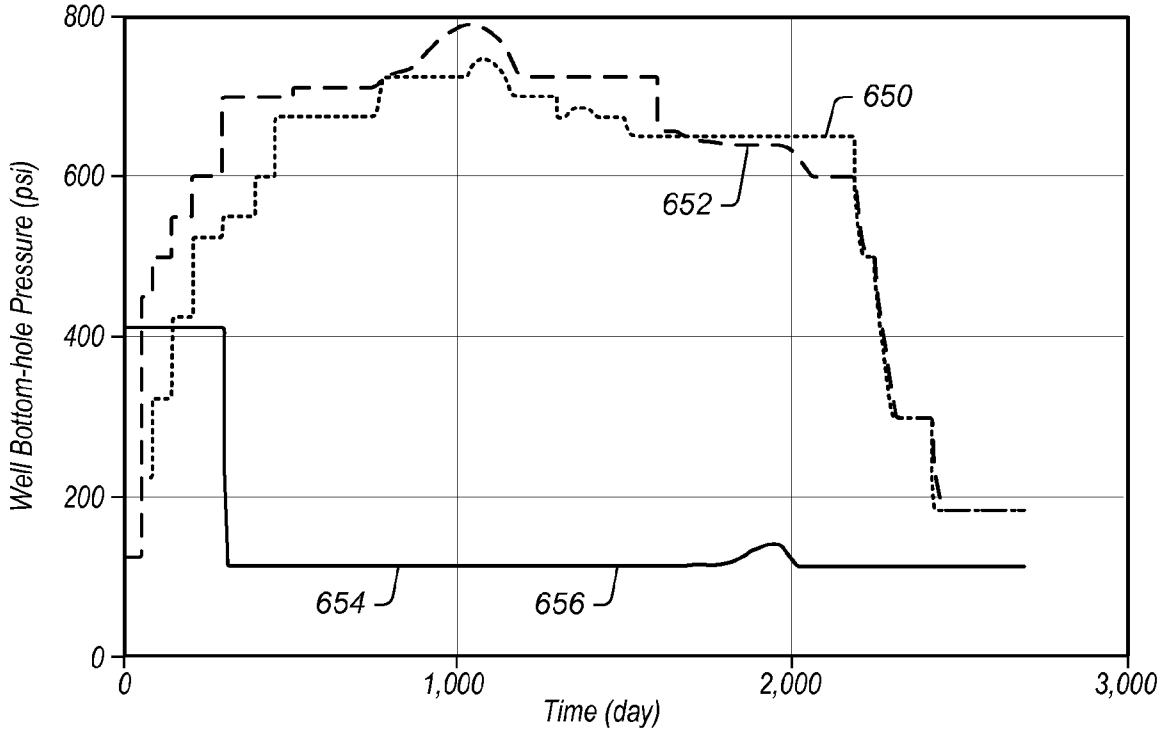


FIG. 148

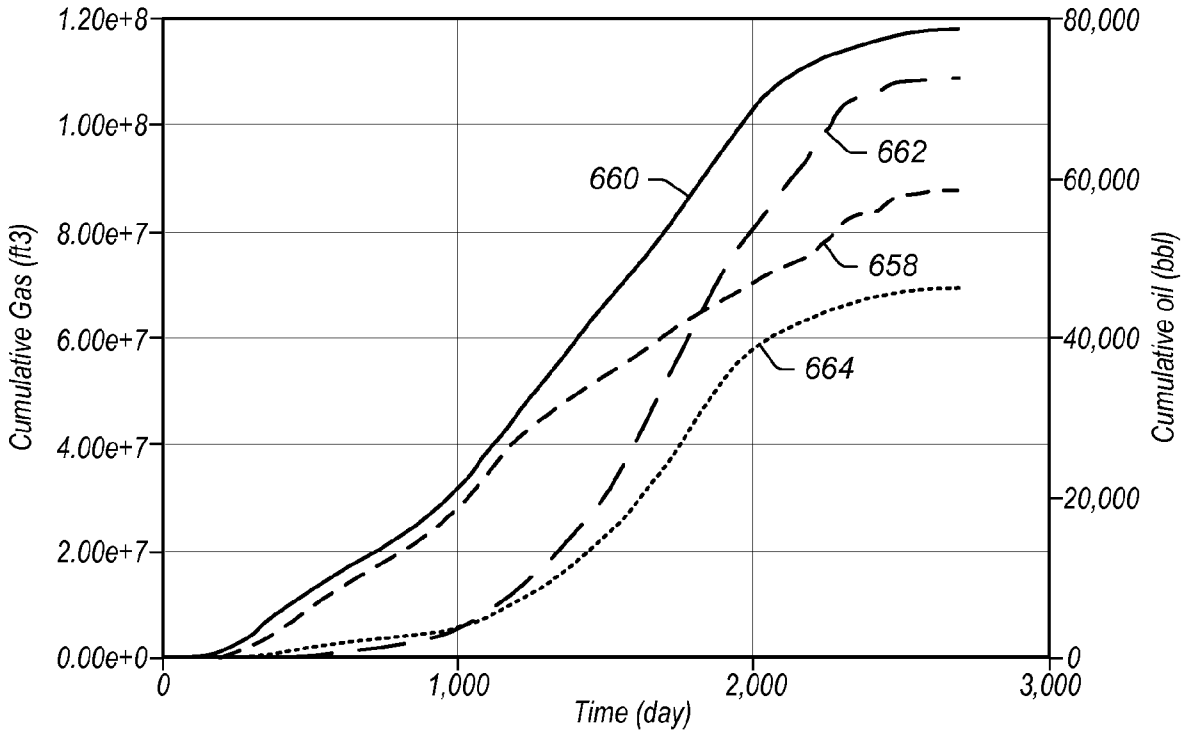


FIG. 149

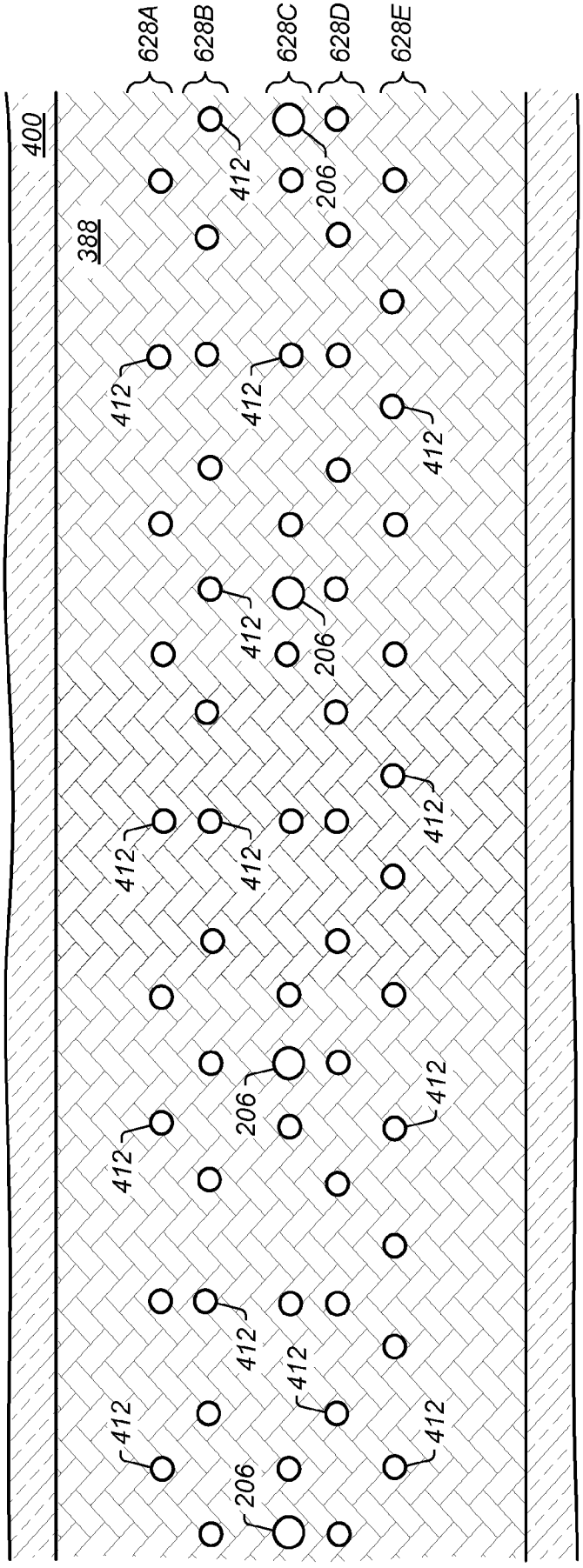


FIG. 150

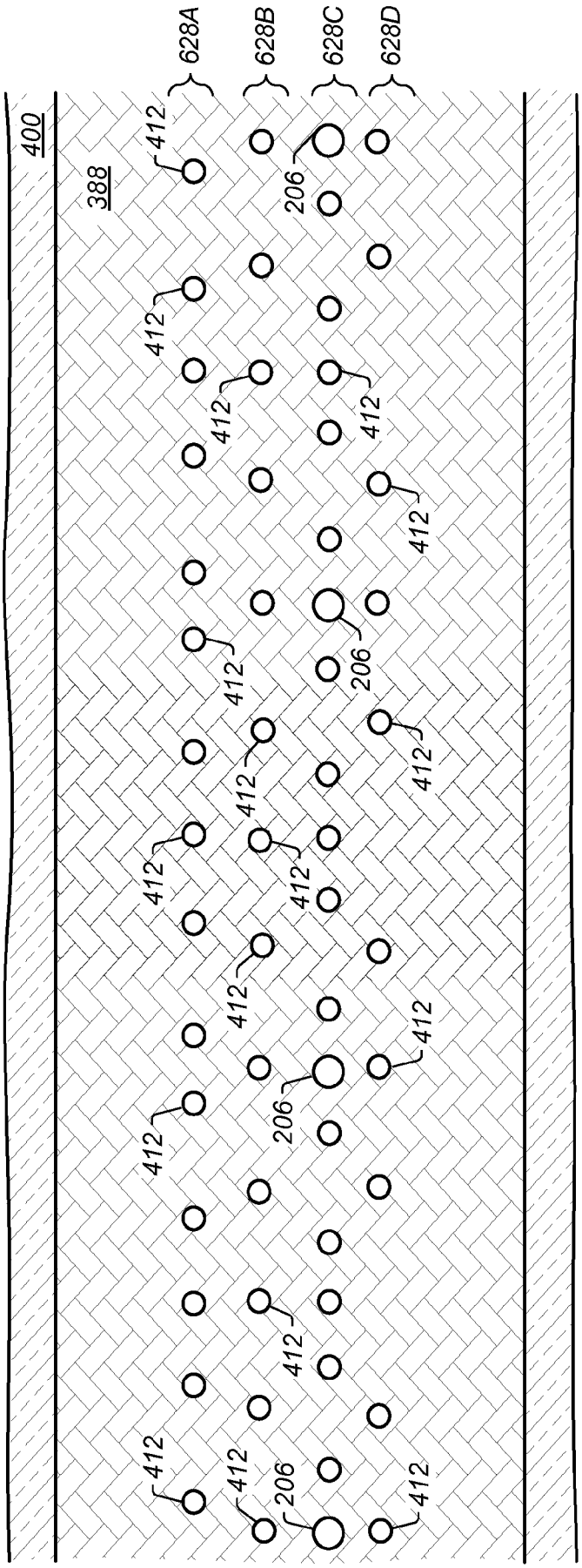


FIG. 151

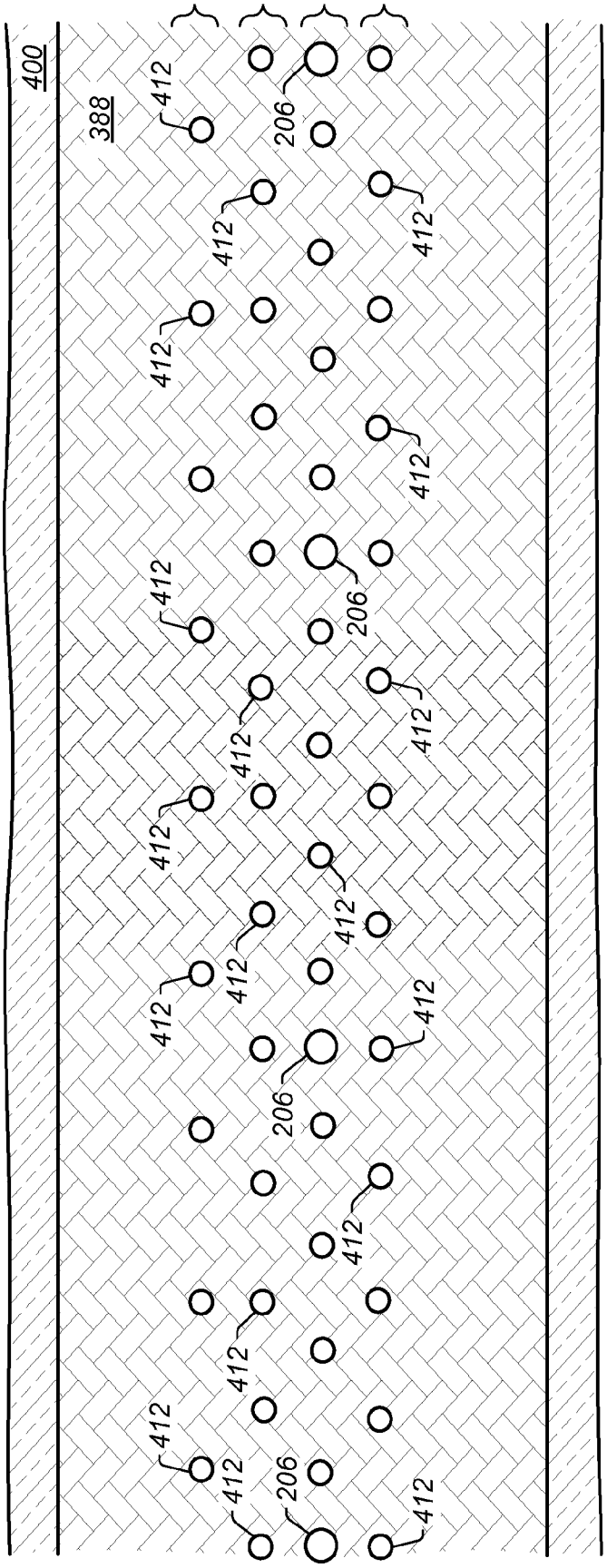


FIG. 152

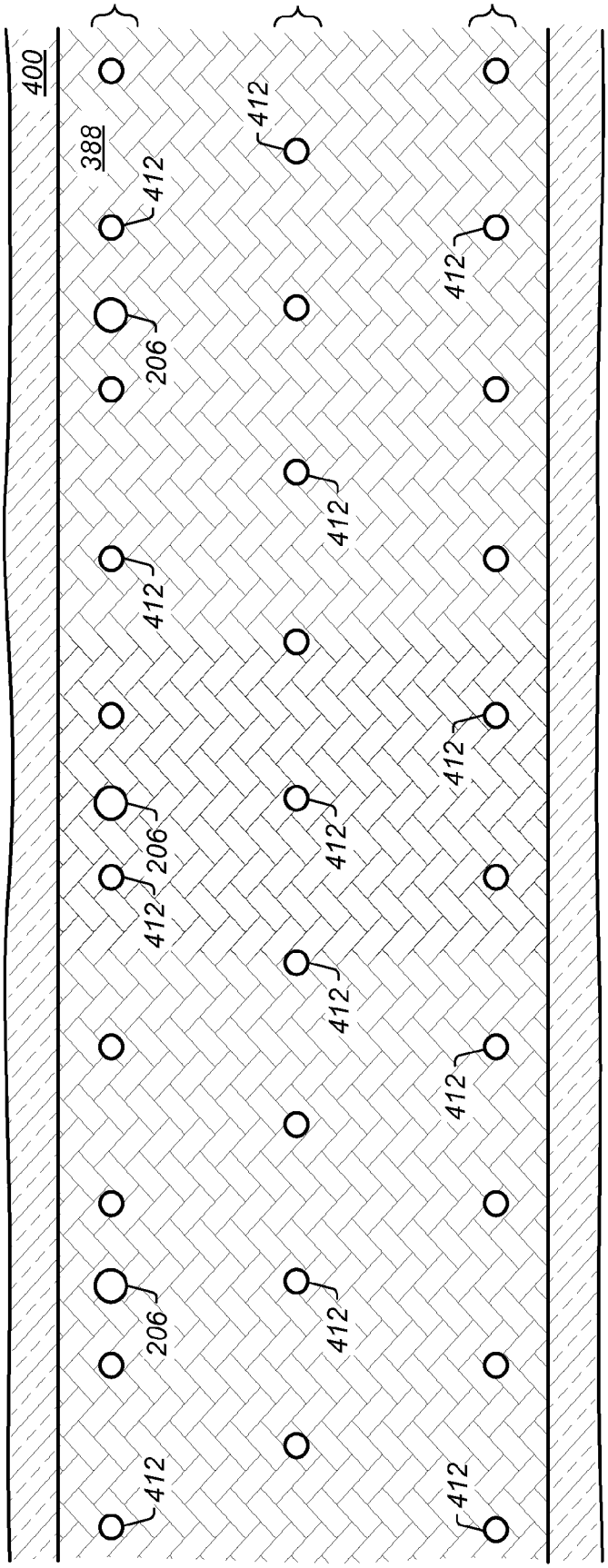


FIG. 153

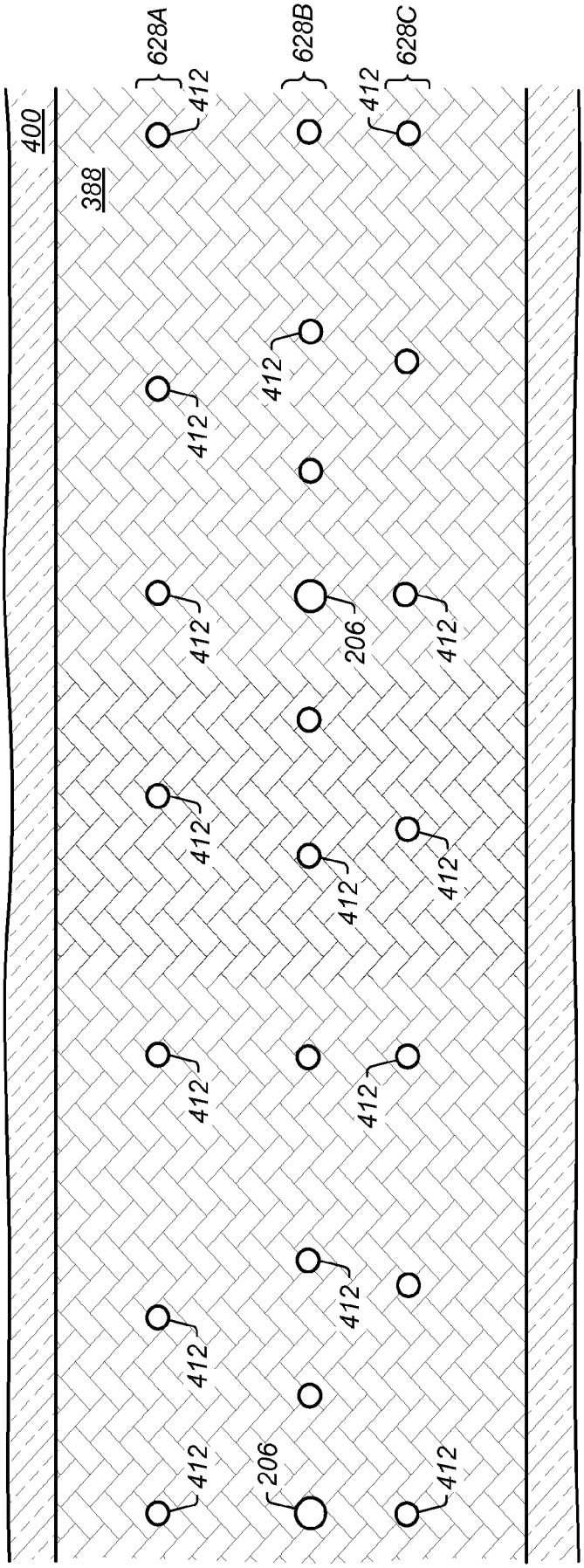


FIG. 154

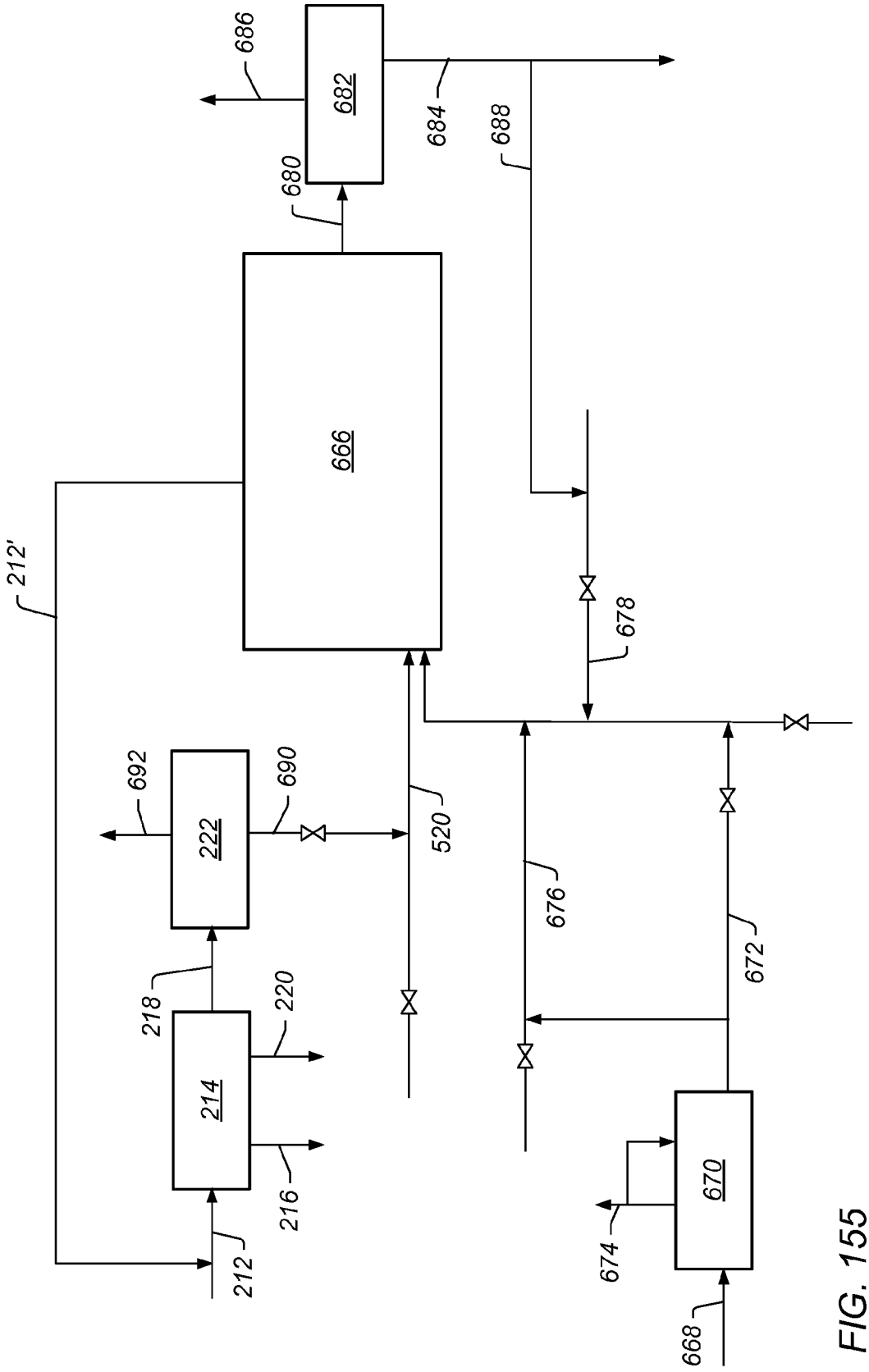

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FIG. 155

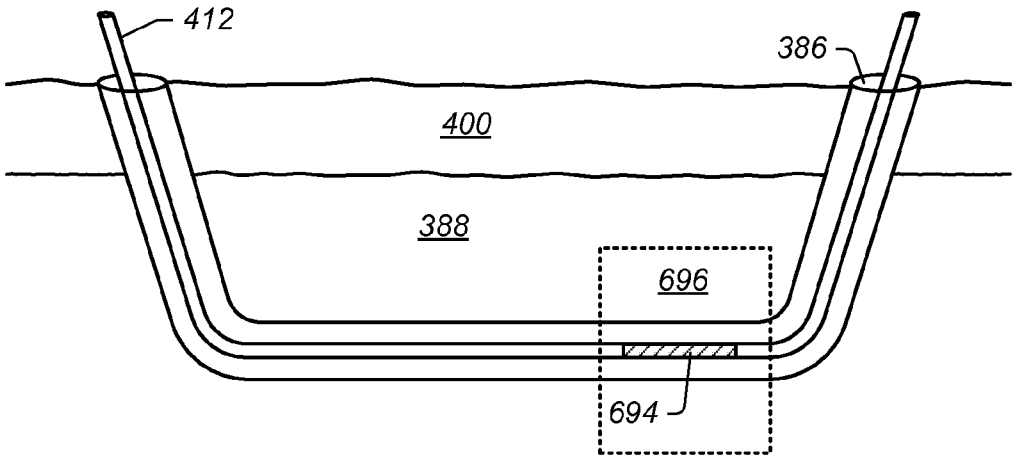


FIG. 156

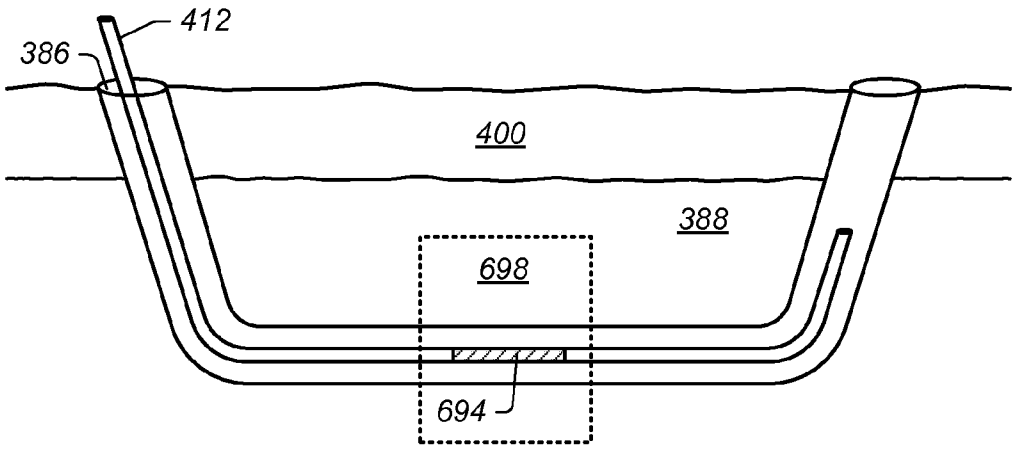


FIG. 157

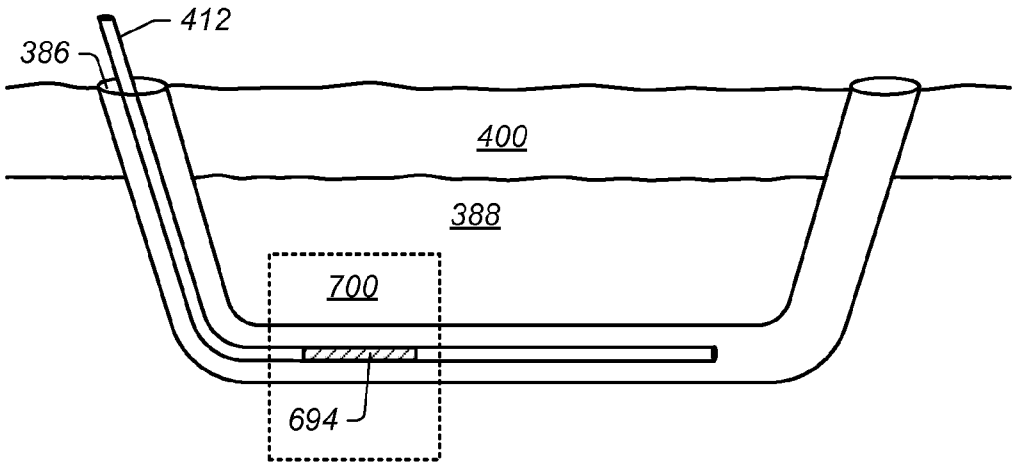


FIG. 158

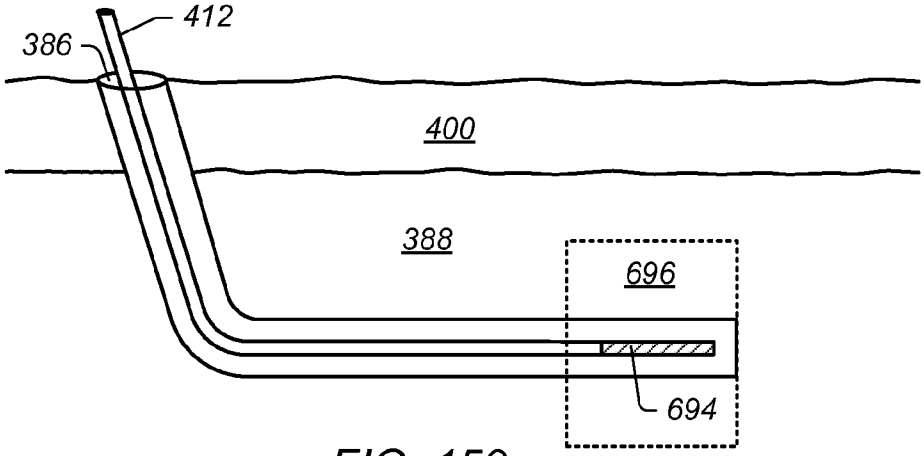


FIG. 159

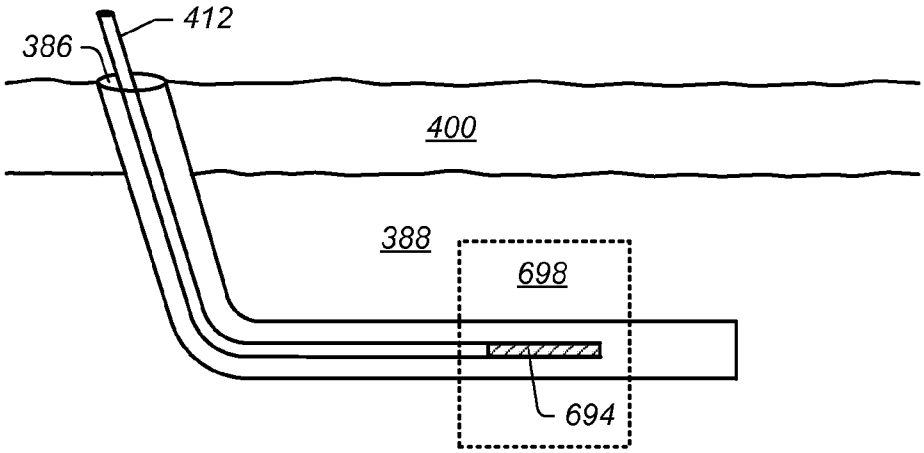


FIG. 160

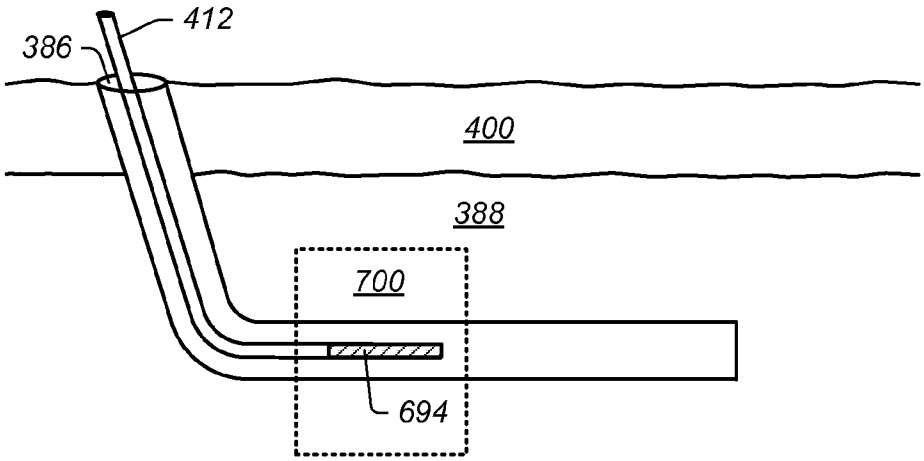


FIG. 161

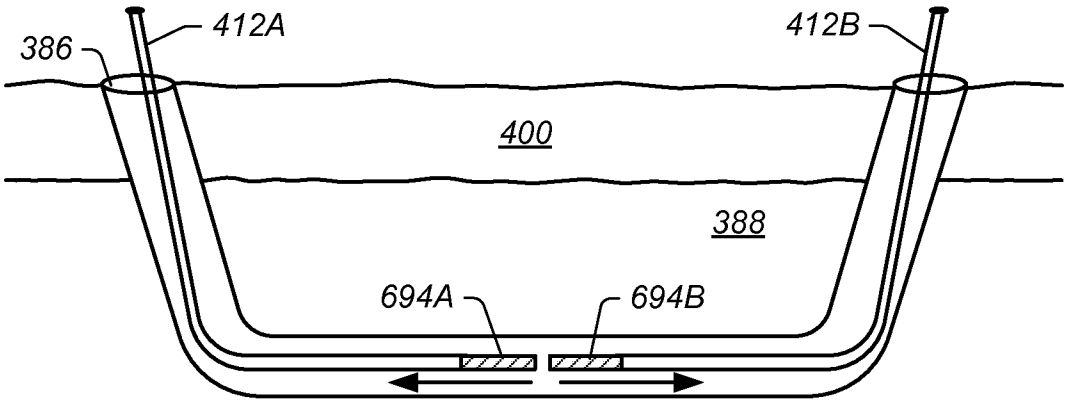


FIG. 162

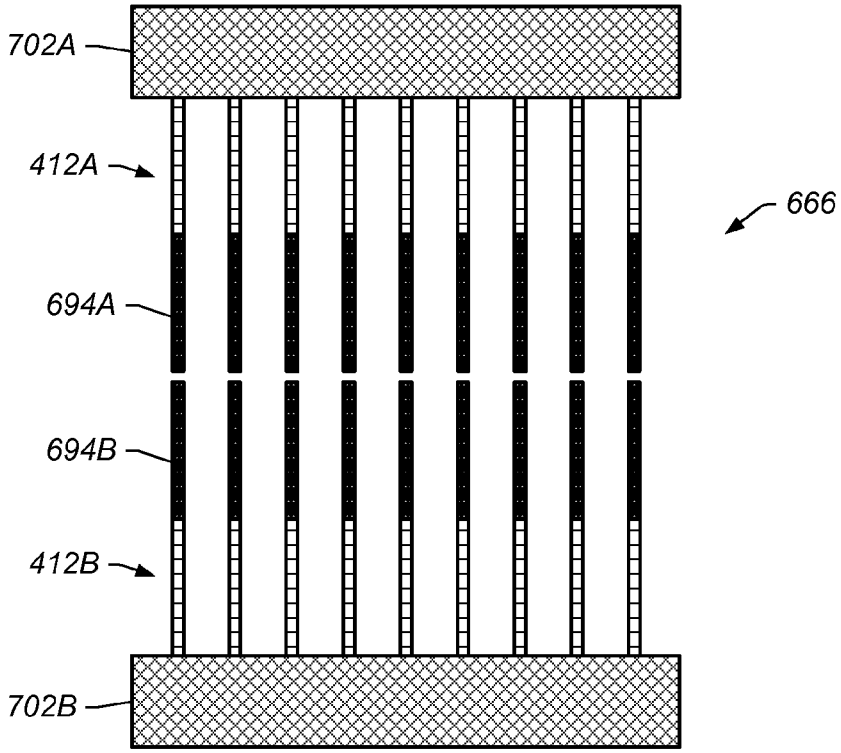


FIG. 163

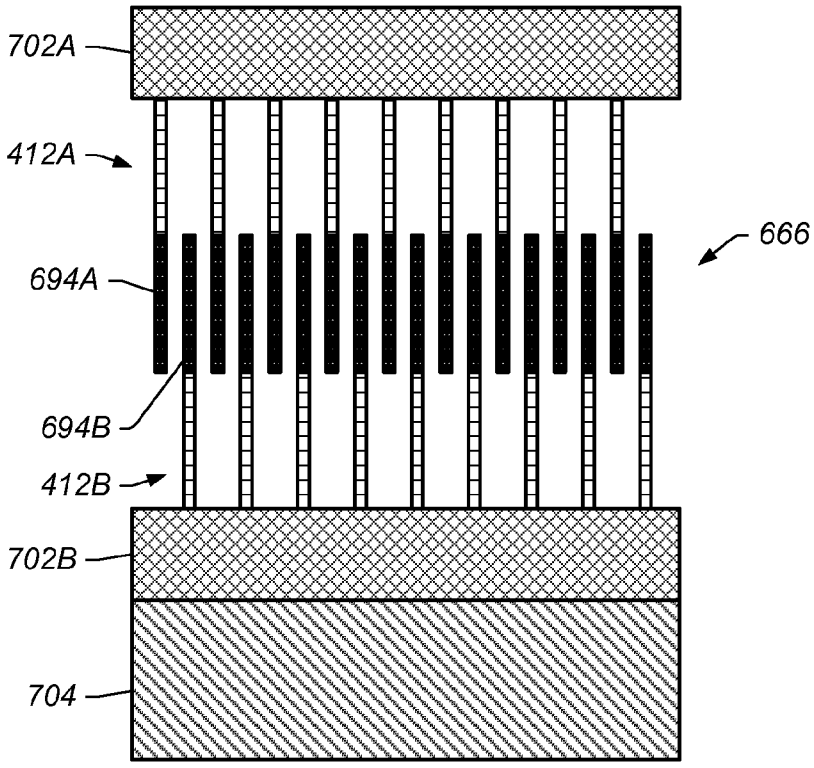


FIG. 164

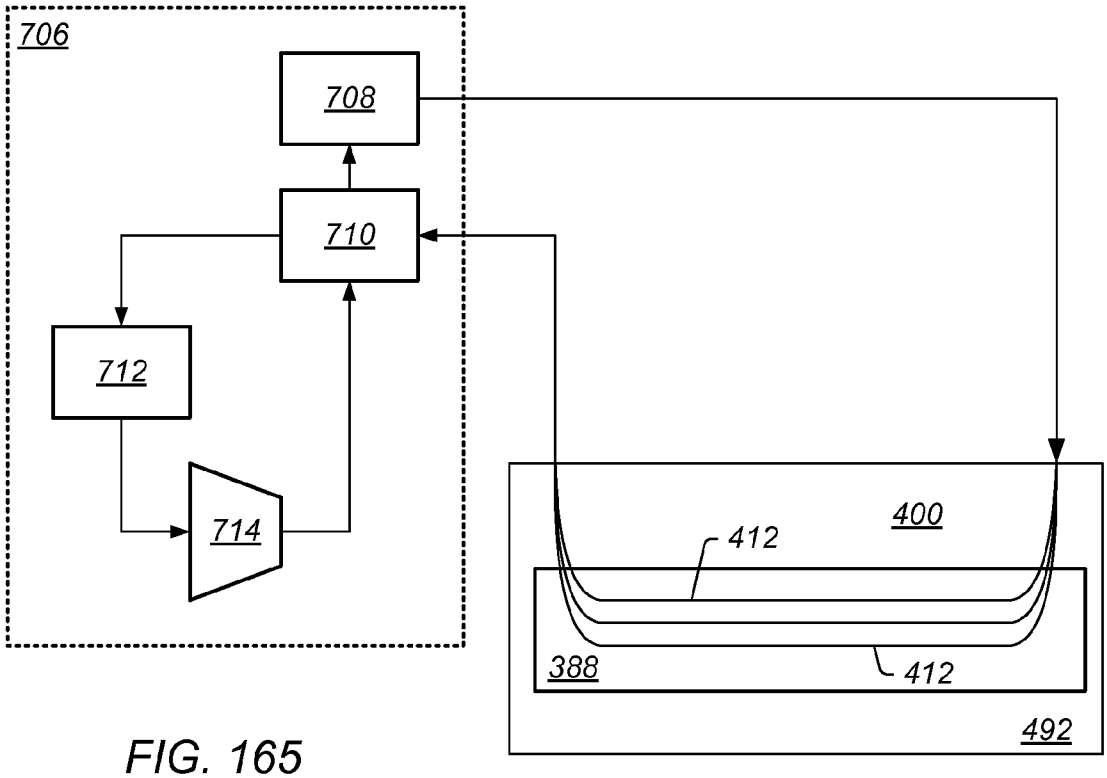


FIG. 165

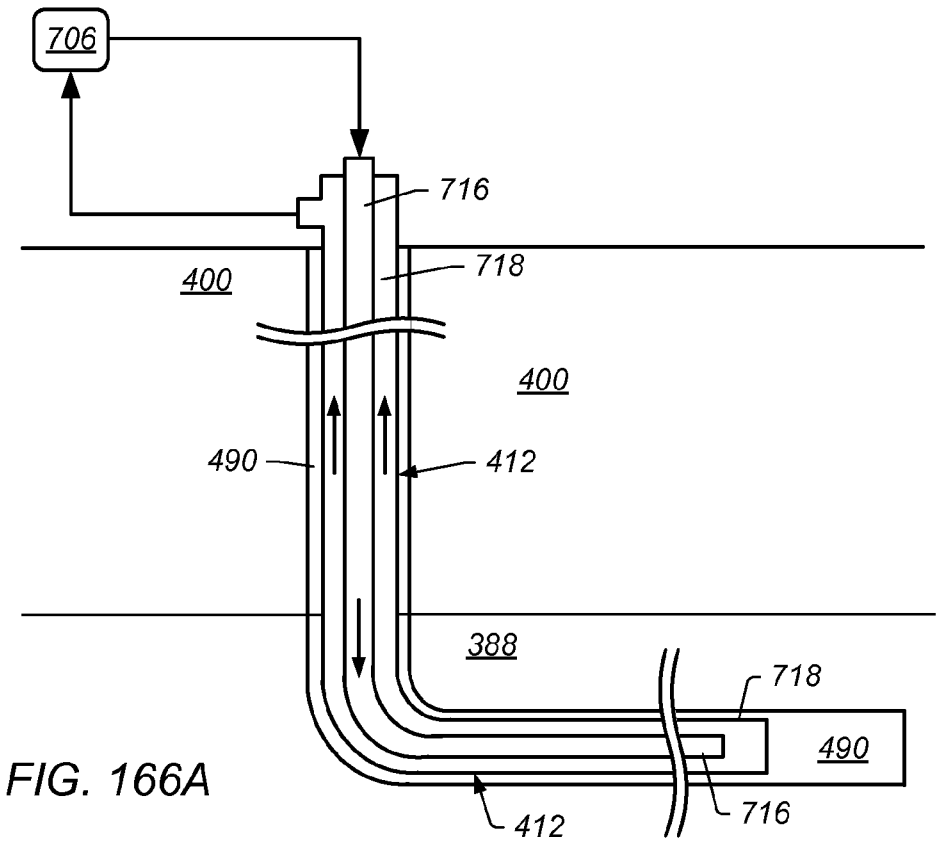


FIG. 166A

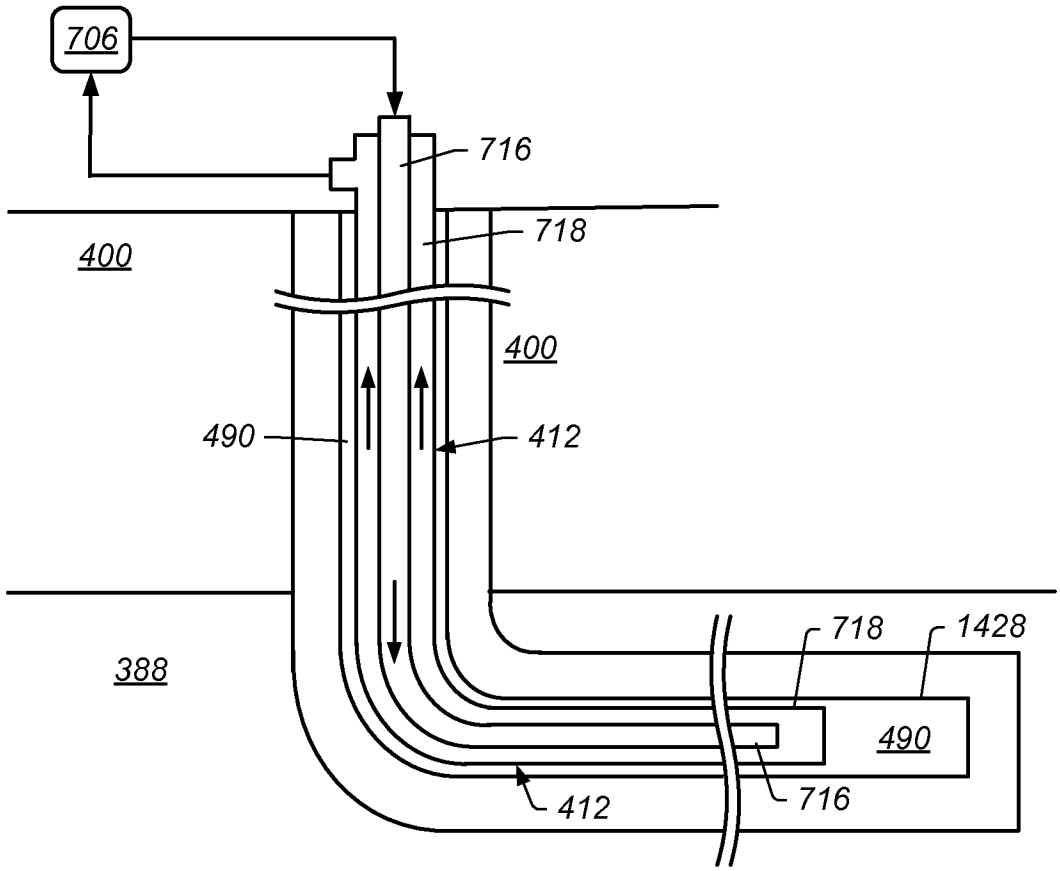


FIG. 166B

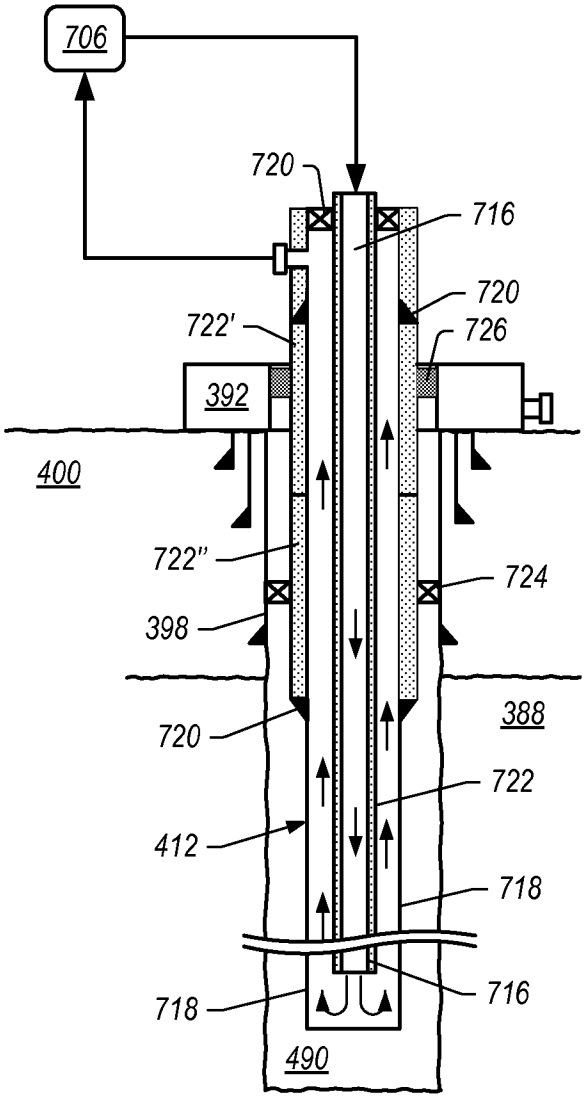


FIG. 167

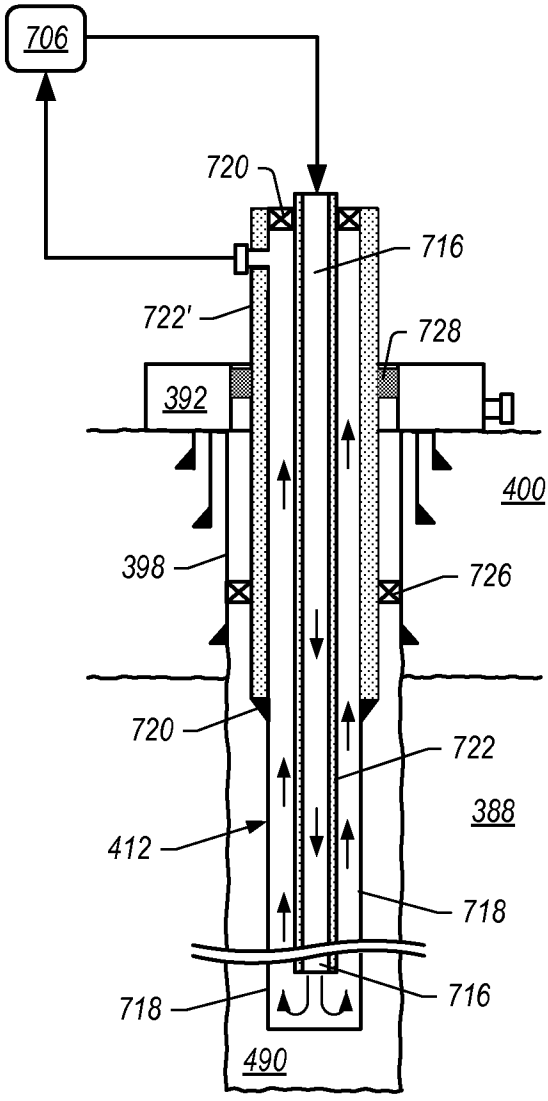


FIG. 168

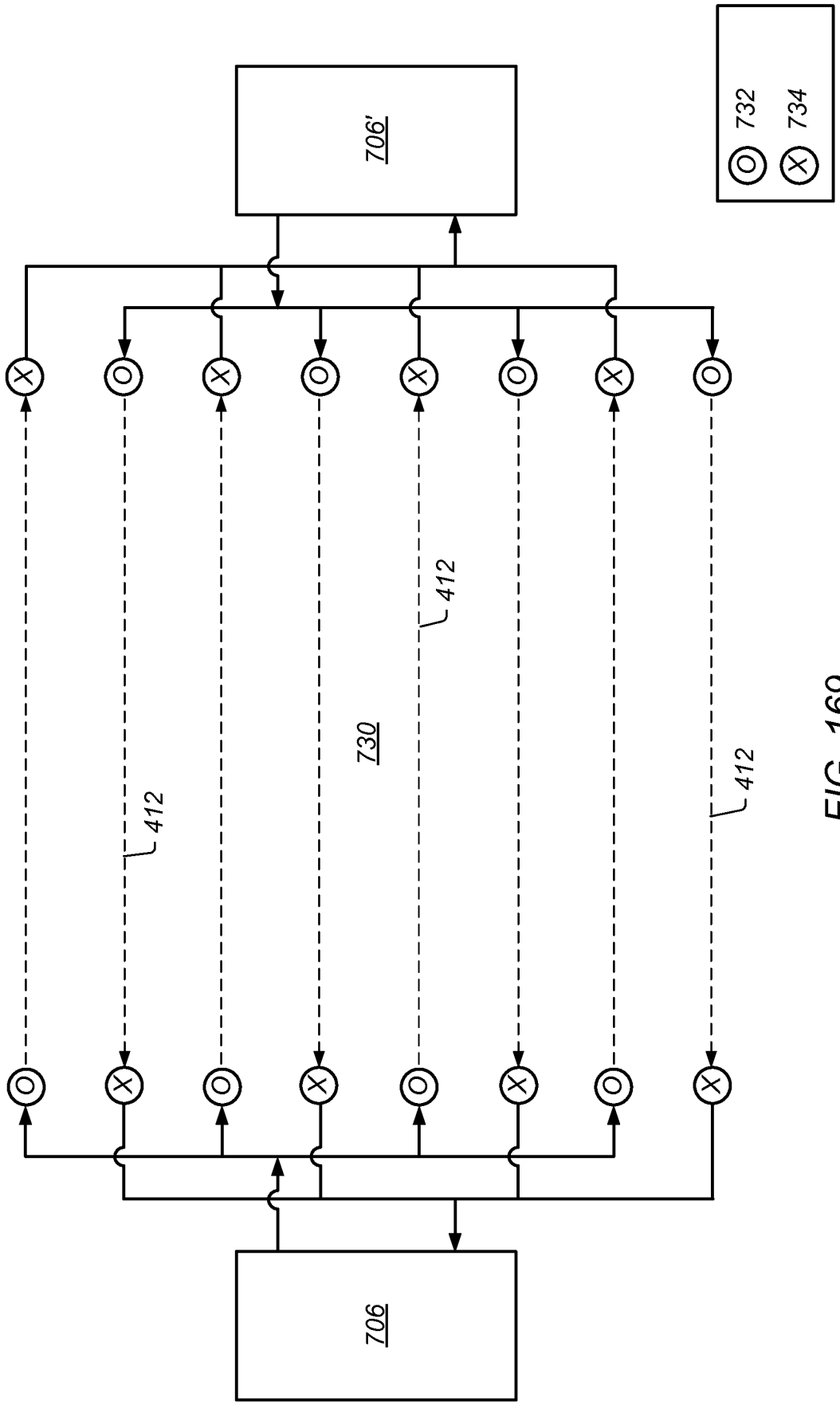


FIG. 169

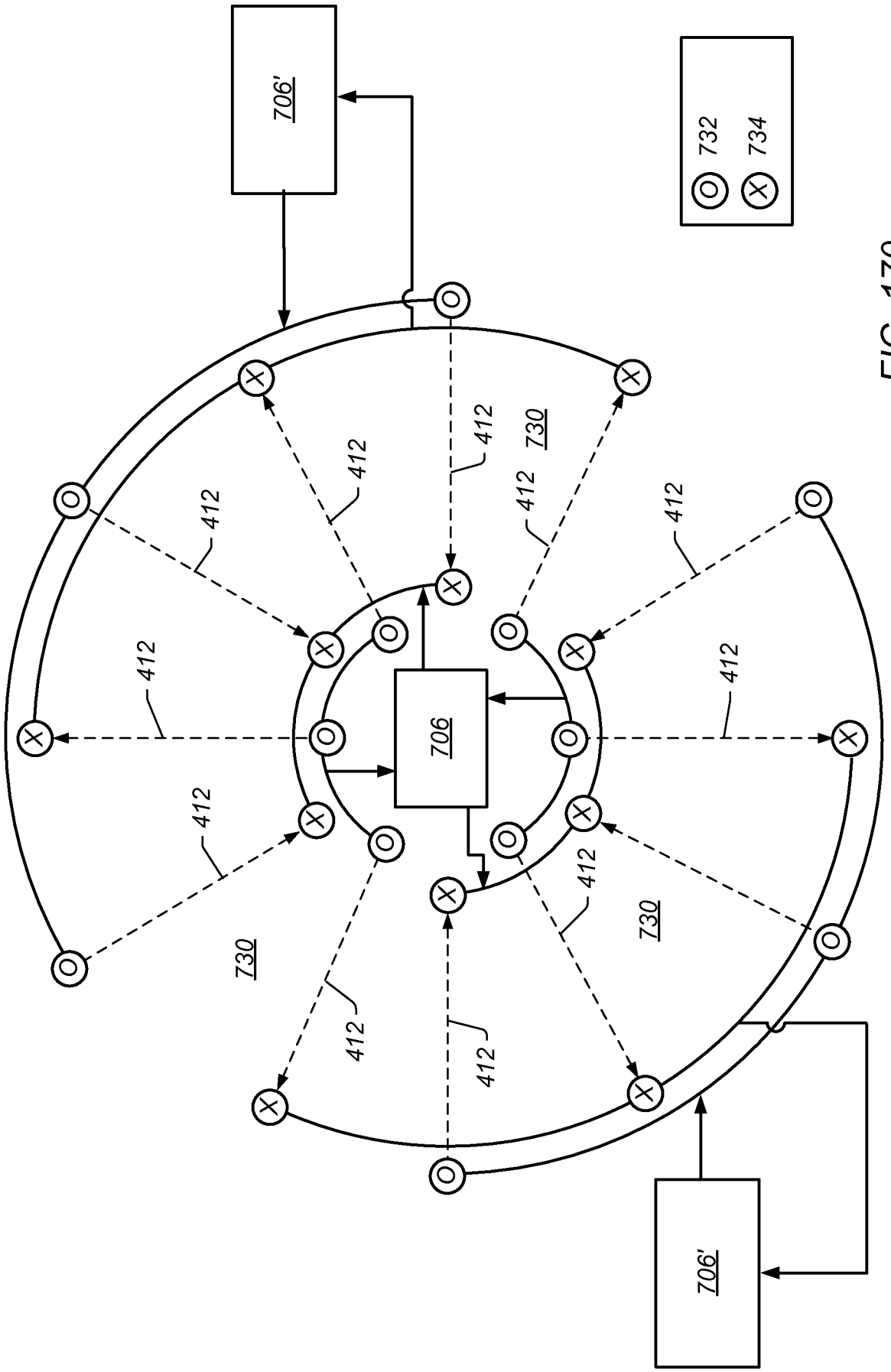


FIG. 170

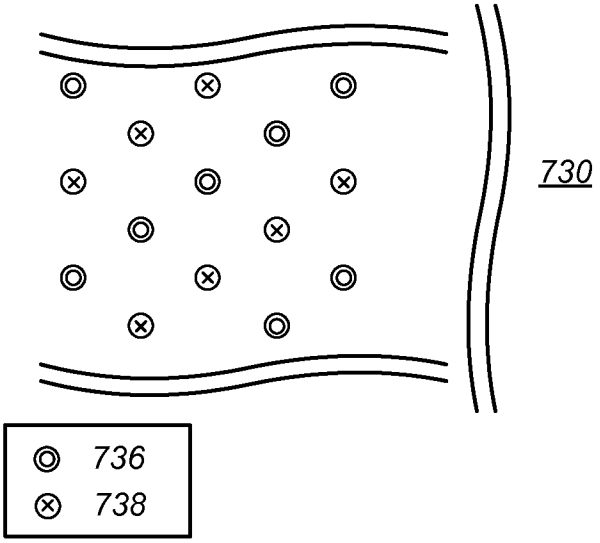


FIG. 171

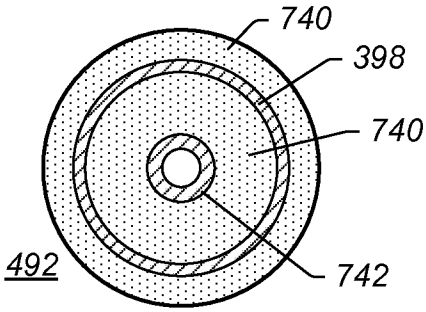


FIG. 172

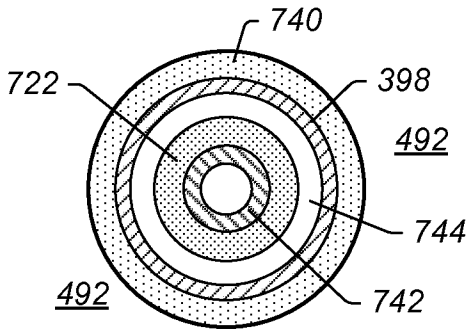


FIG. 173

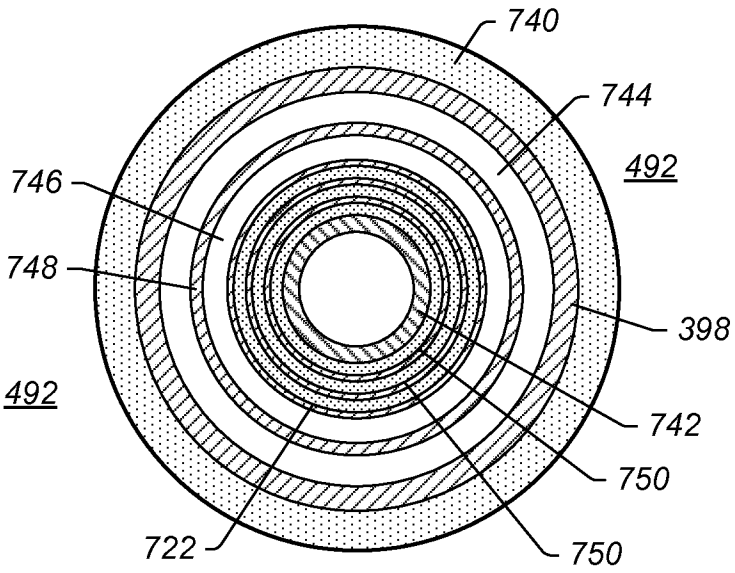


FIG. 174

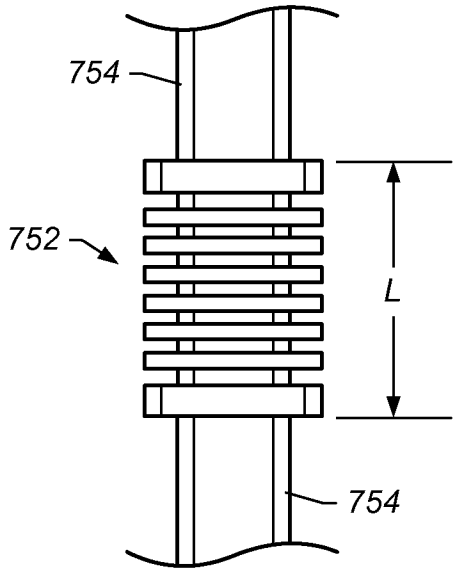


FIG. 175

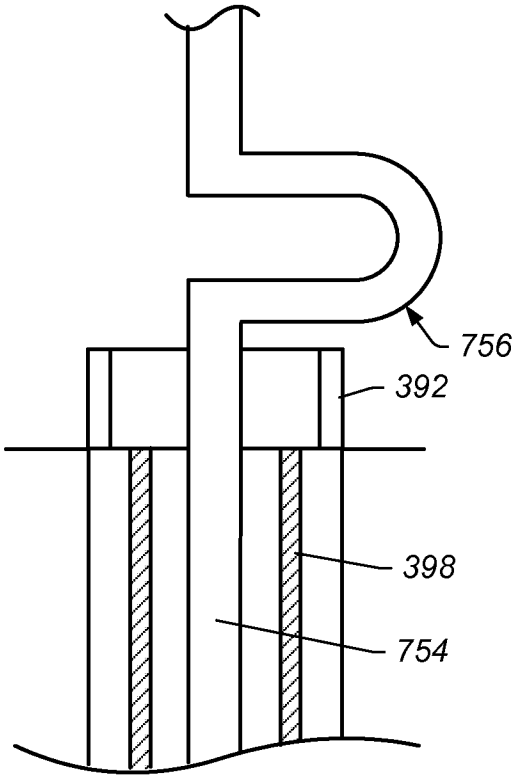


FIG. 176A

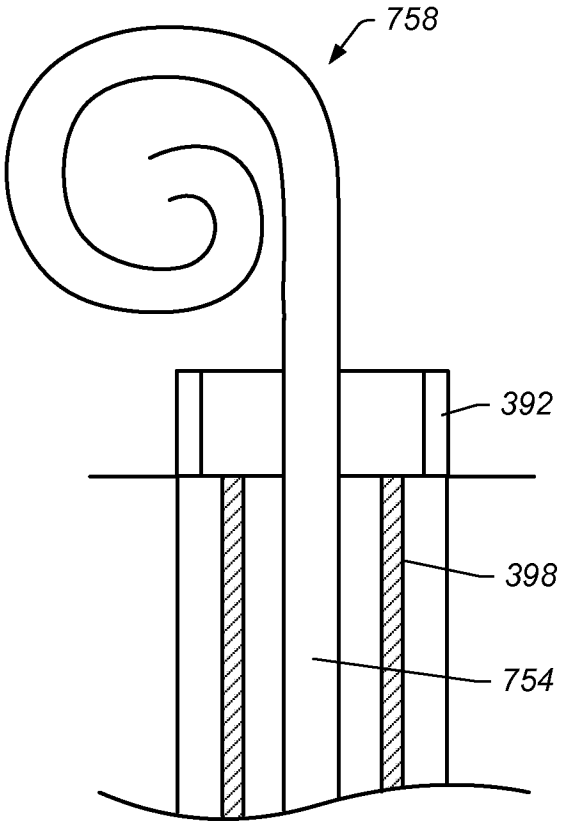


FIG. 176B

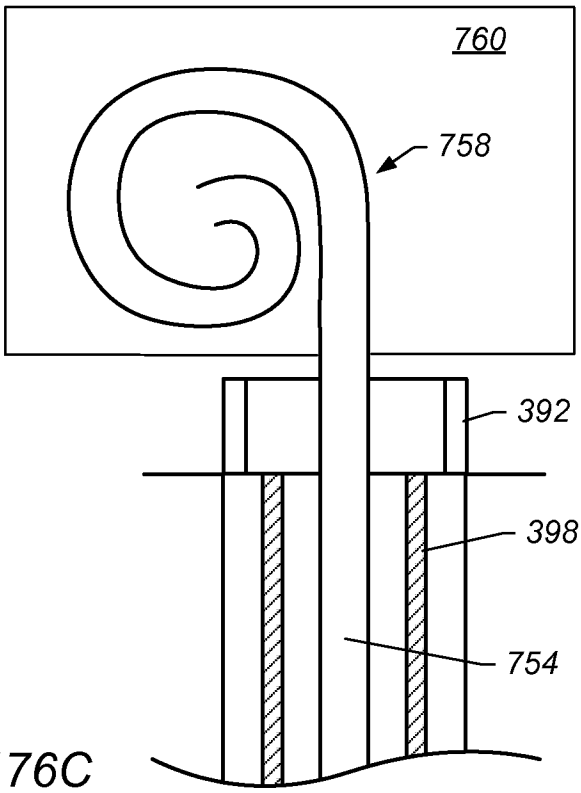


FIG. 176C

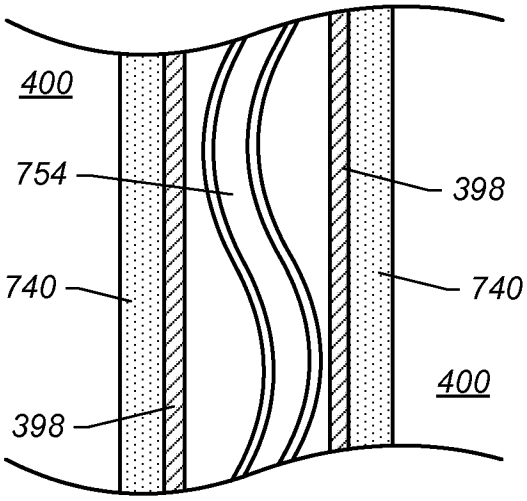


FIG. 177

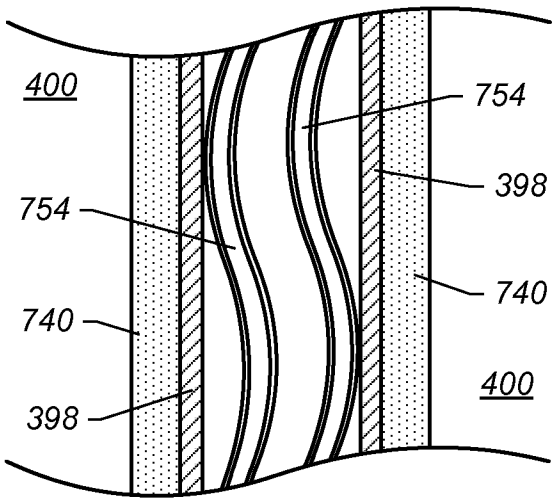


FIG. 178

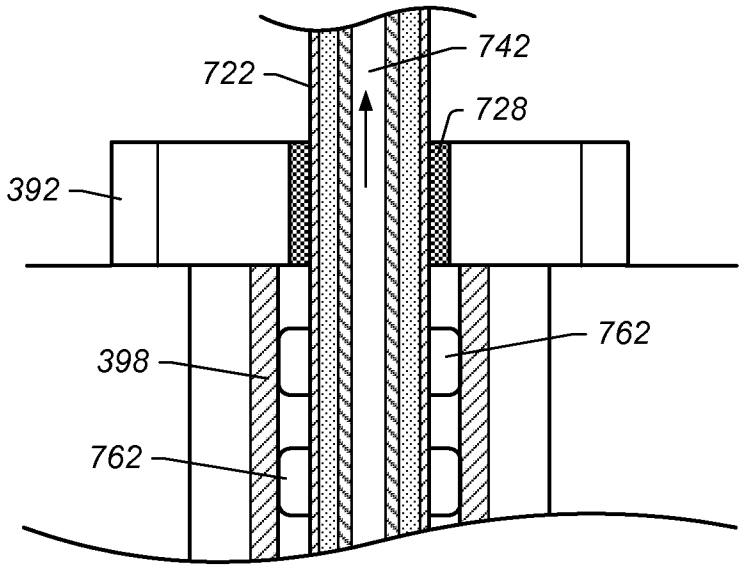


FIG. 179

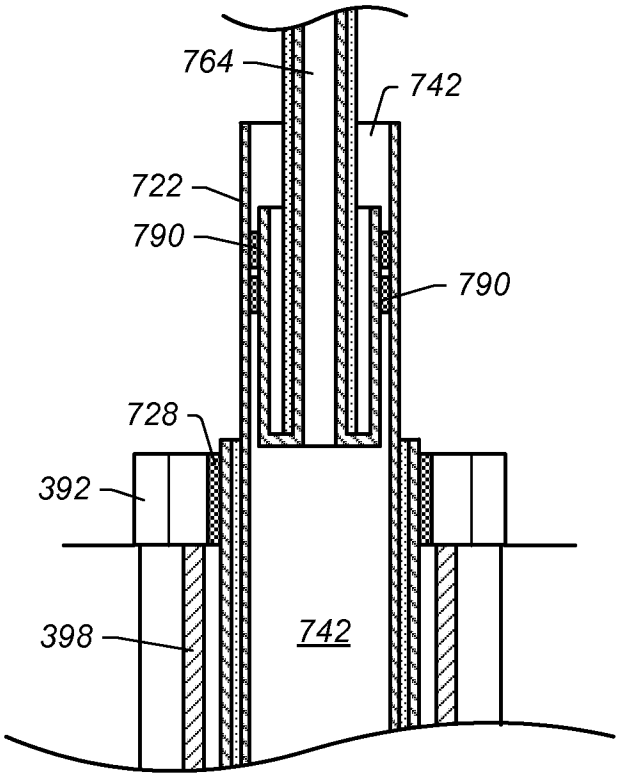


FIG. 180

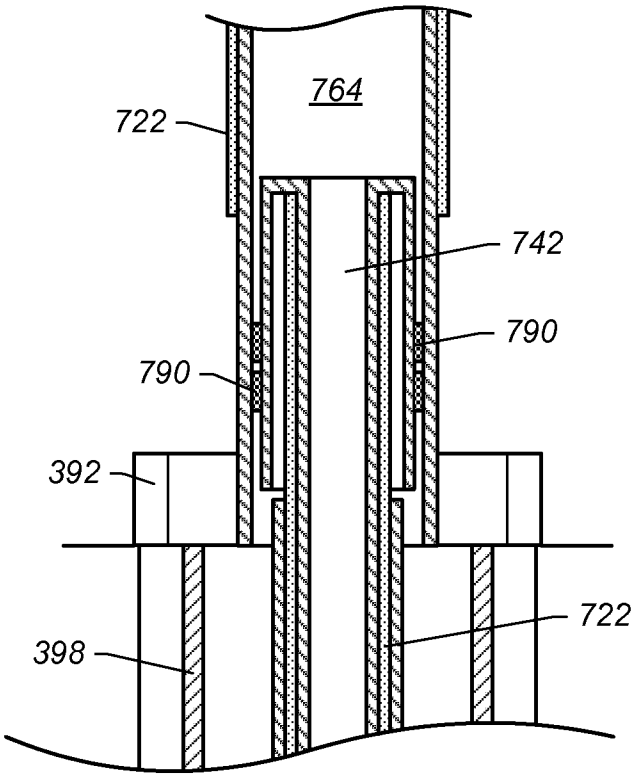


FIG. 181

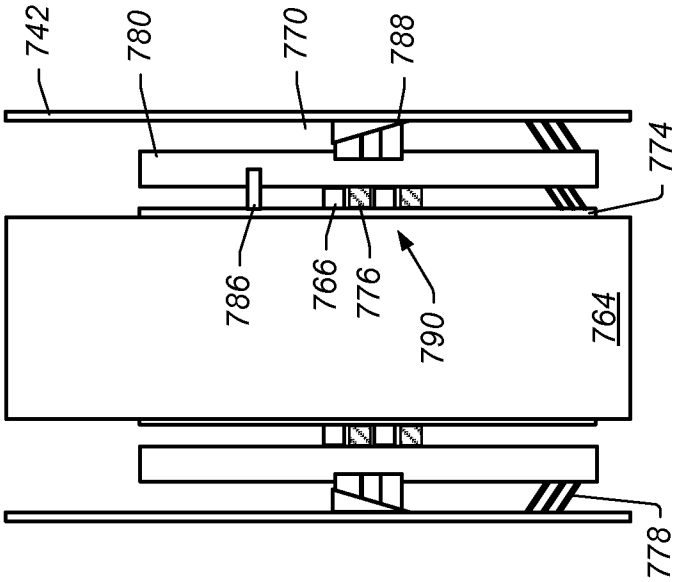


FIG. 184

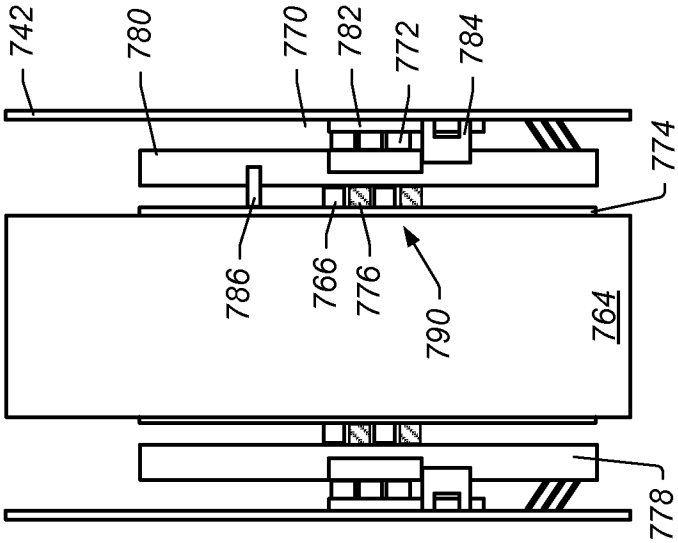


FIG. 183

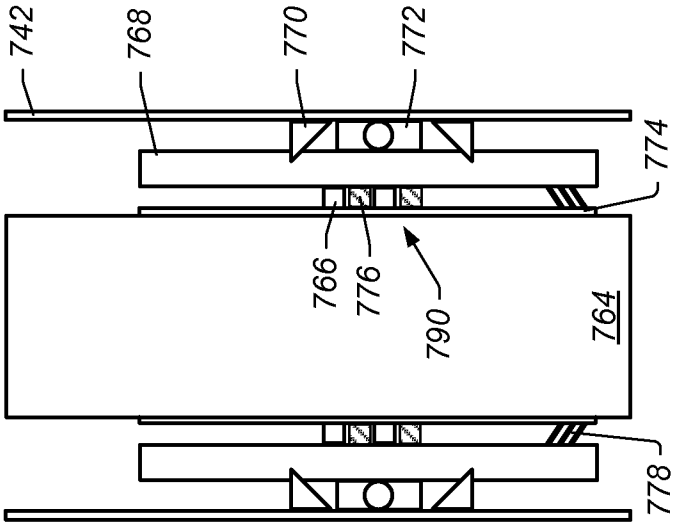


FIG. 182

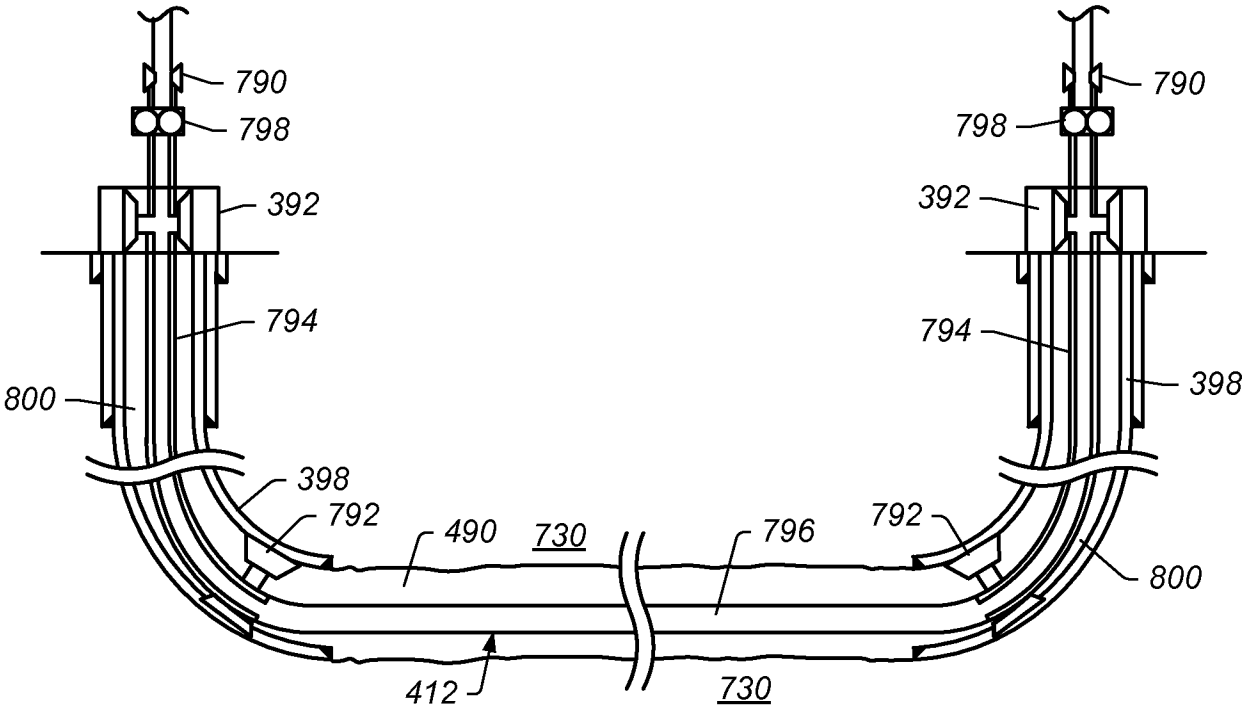


FIG. 185

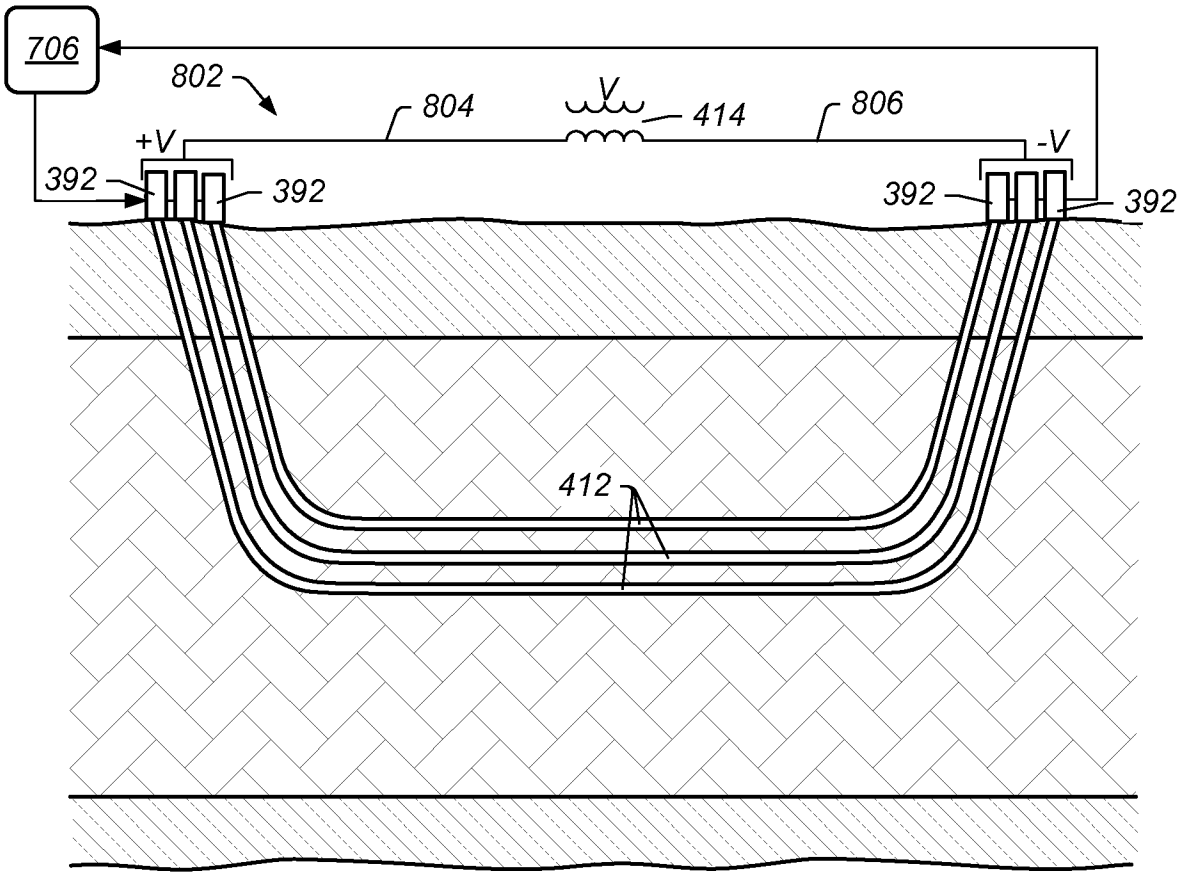


FIG. 186

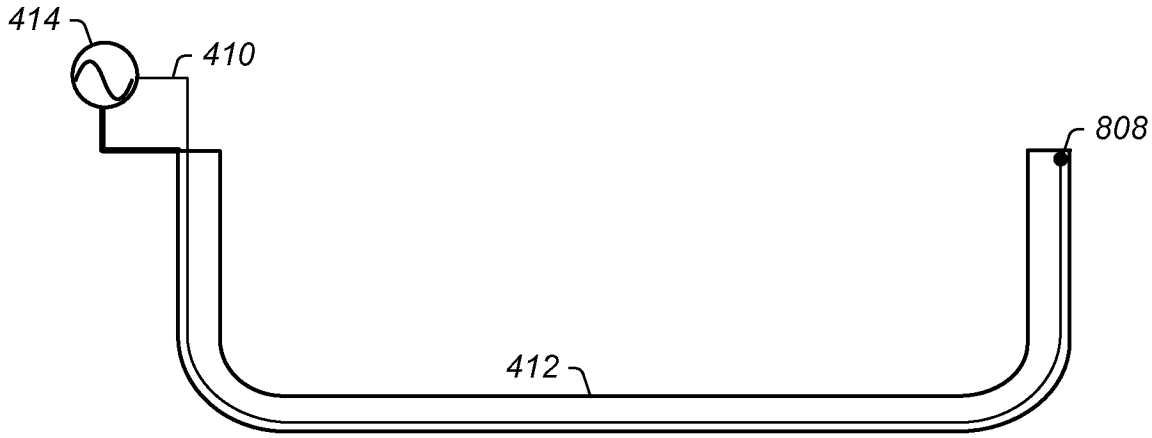


FIG. 187

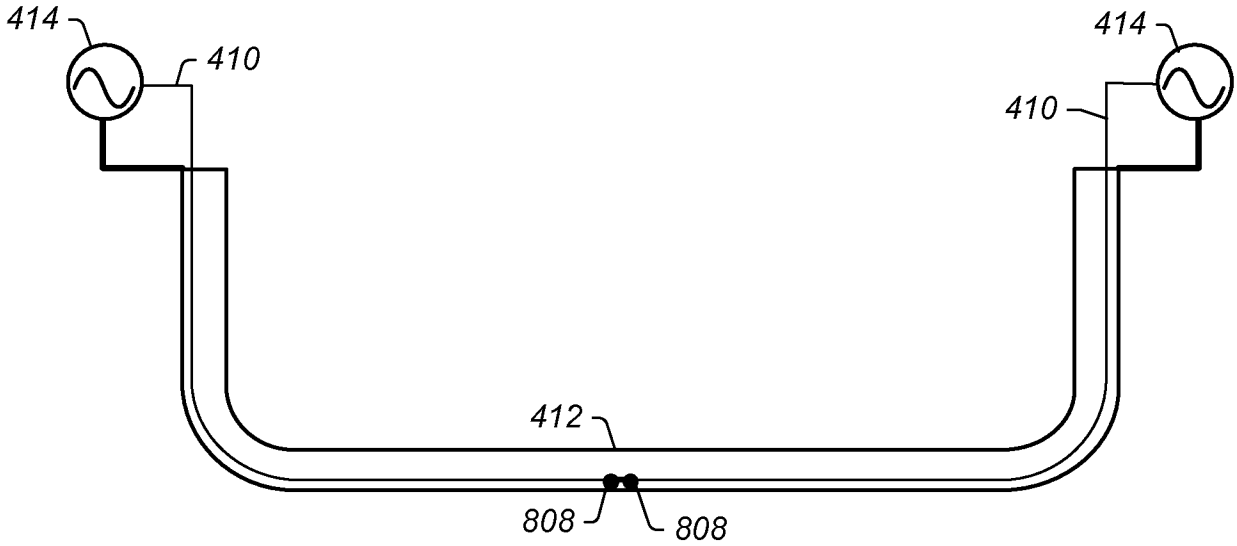


FIG. 188

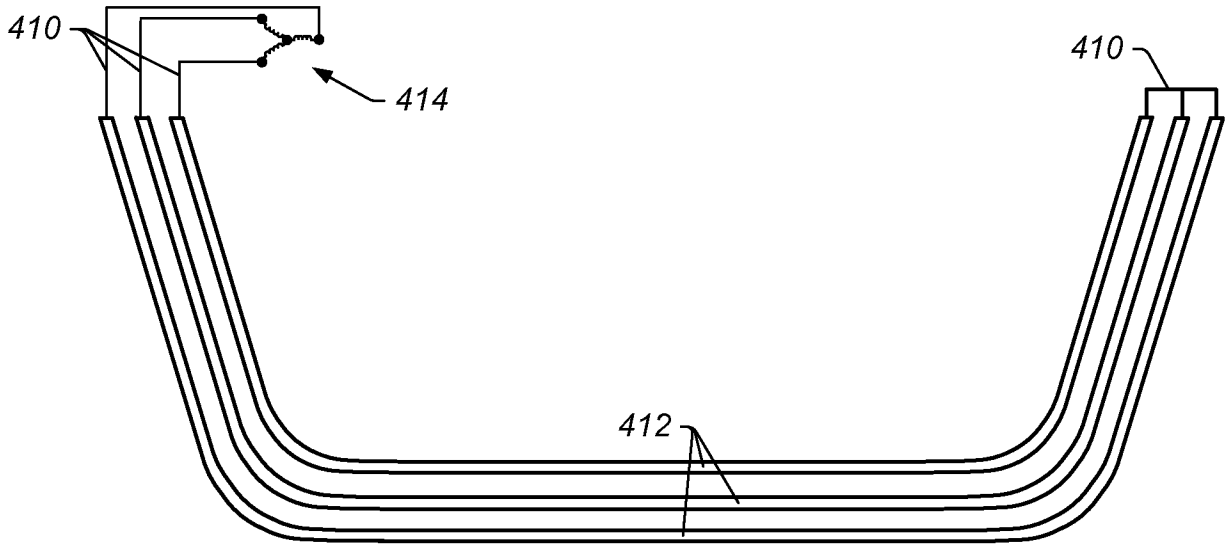


FIG. 189

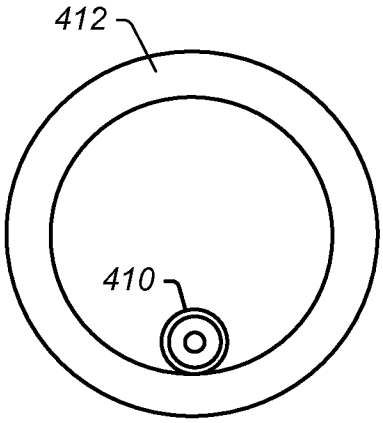


FIG. 190

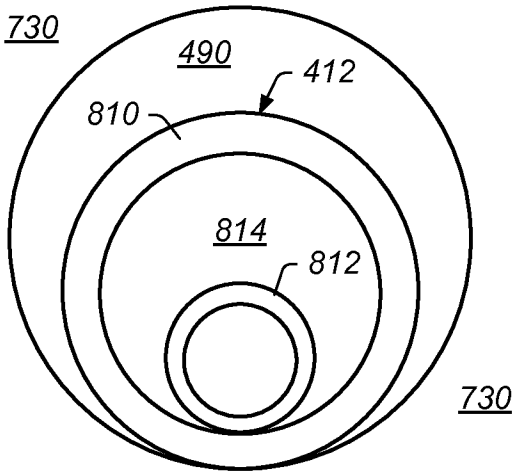


FIG. 191

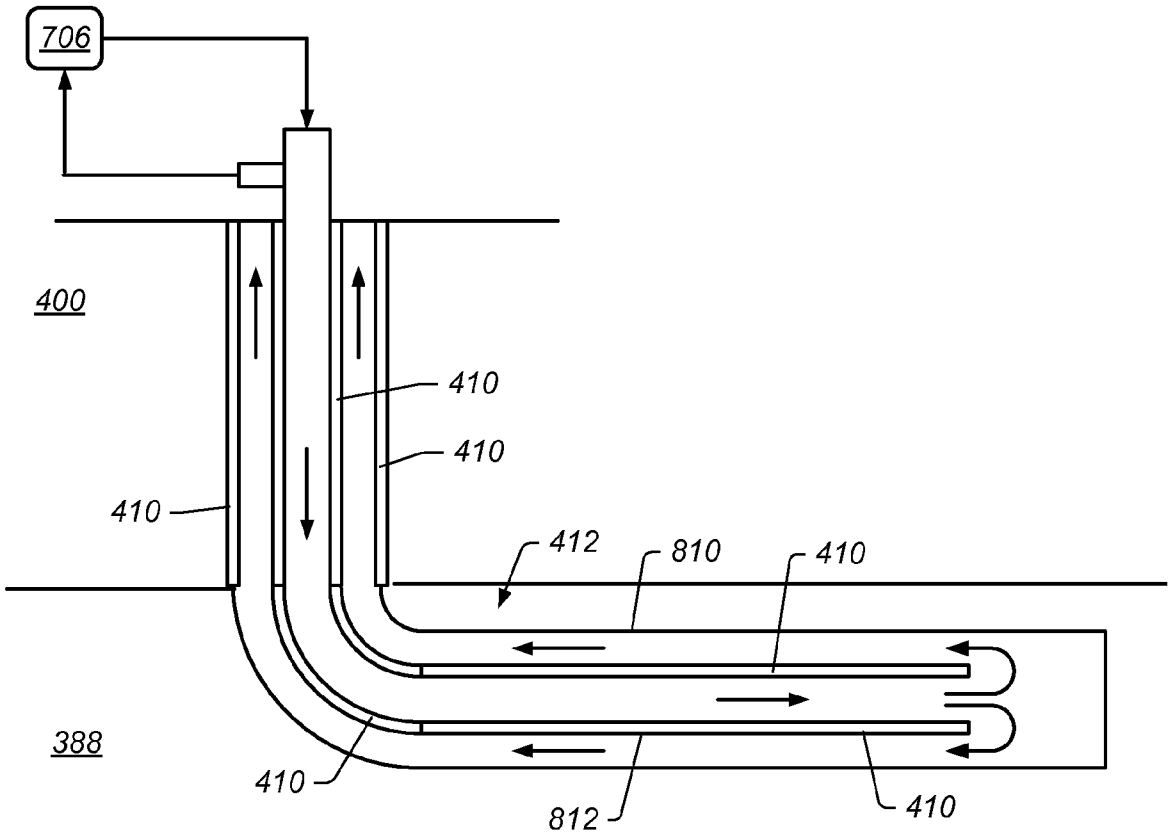


FIG. 192

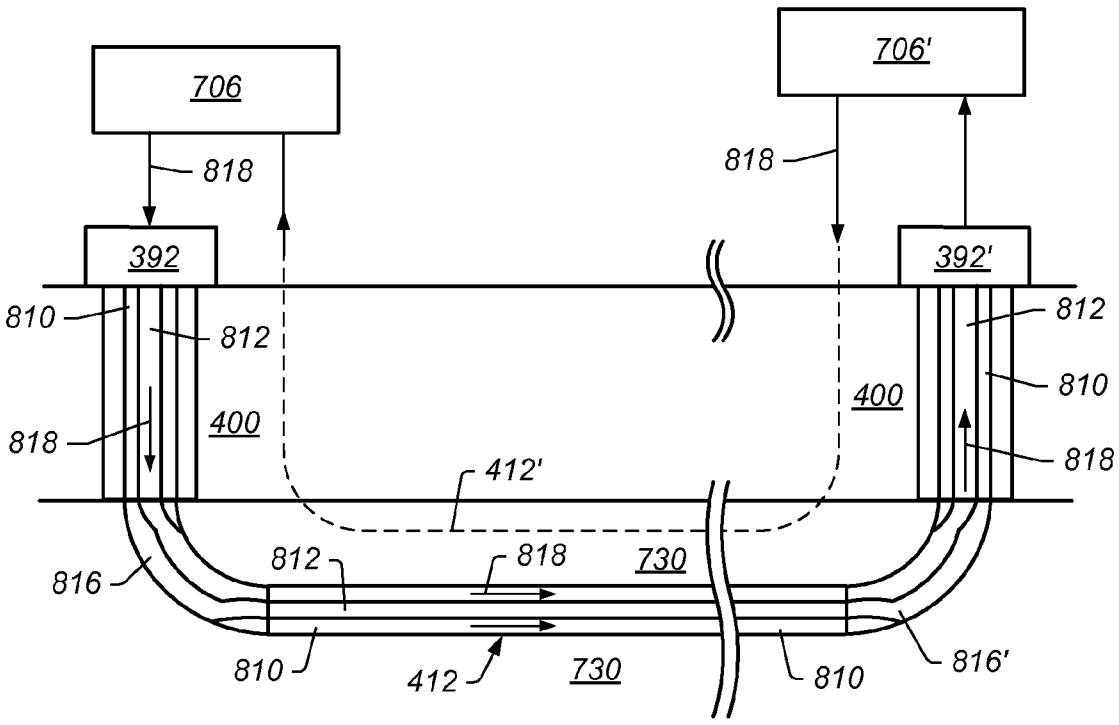


FIG. 193

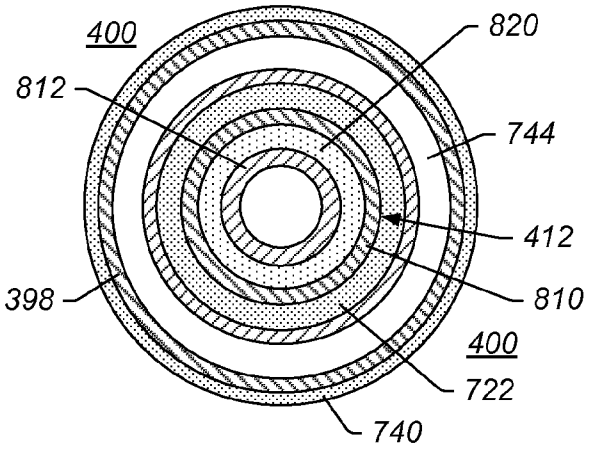


FIG. 194

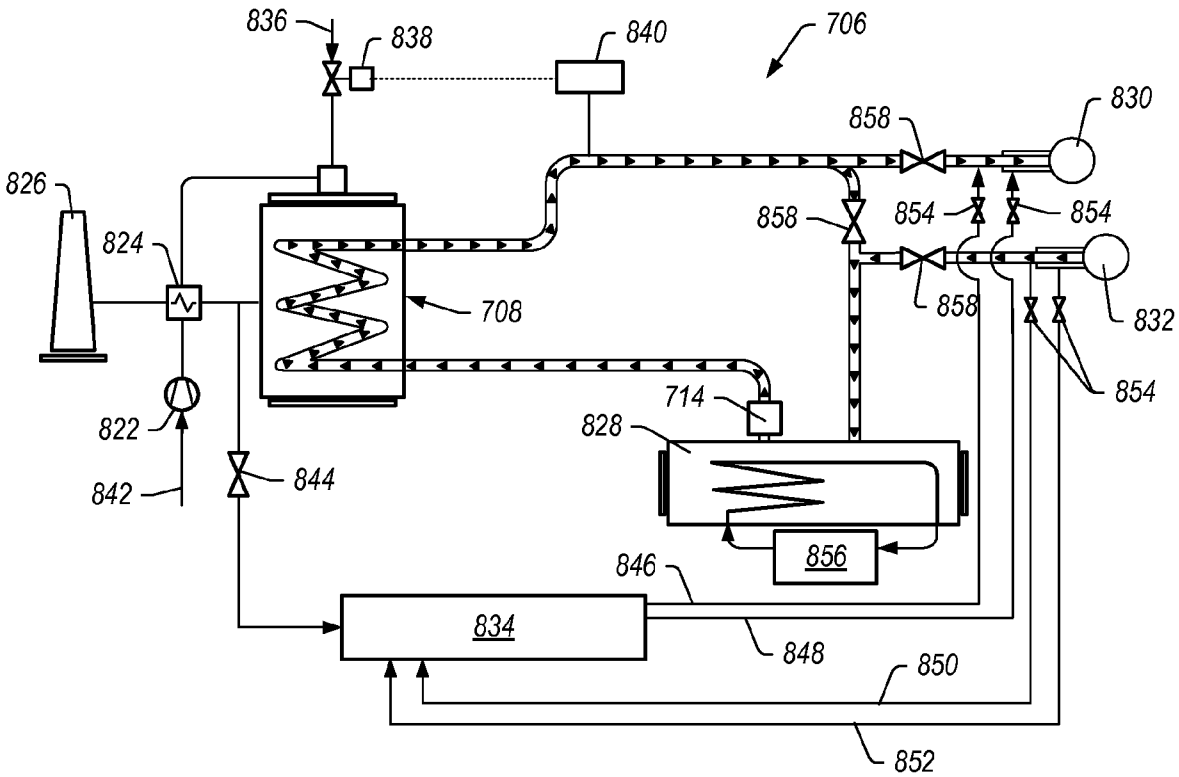


FIG. 195

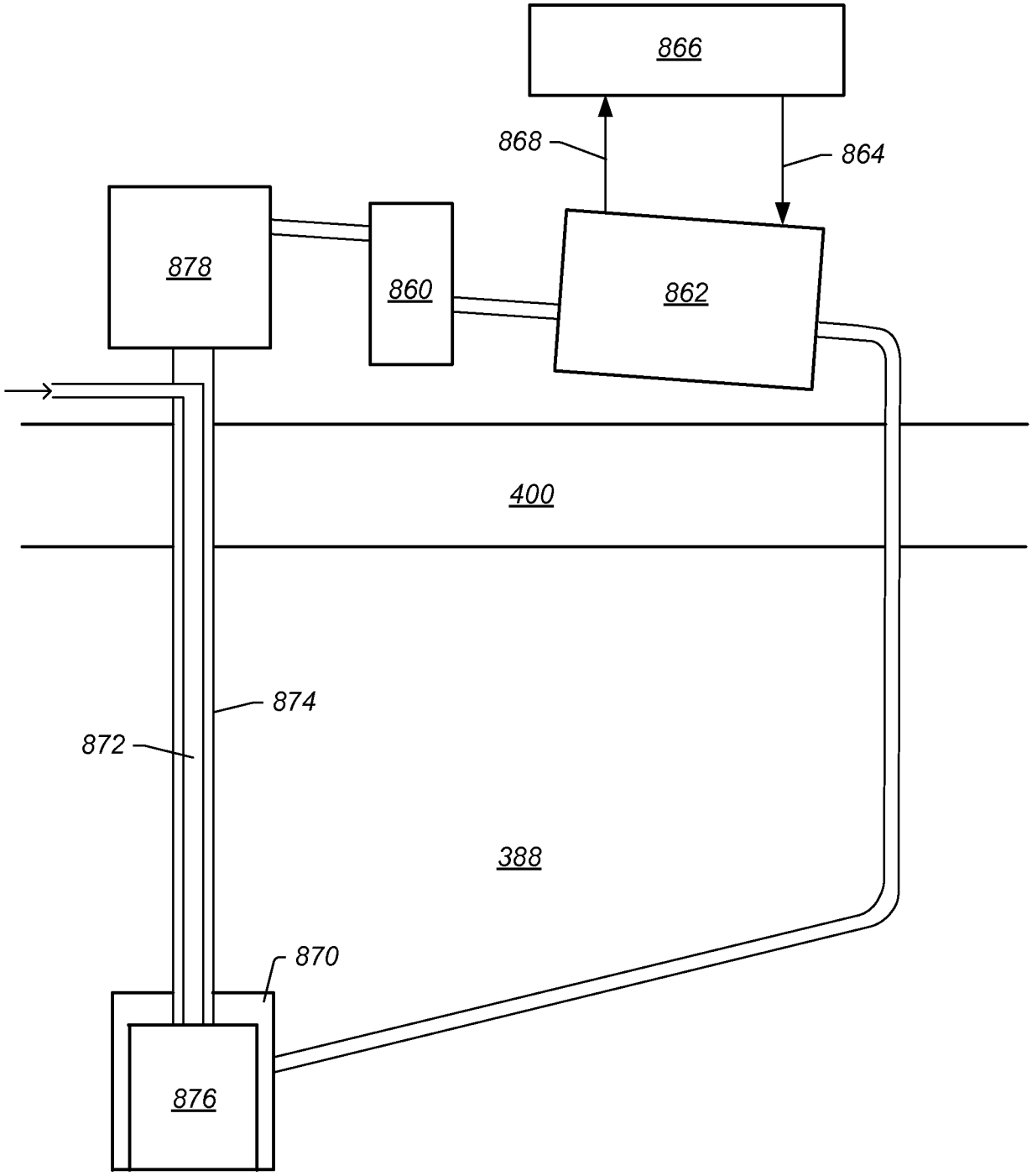


FIG. 196

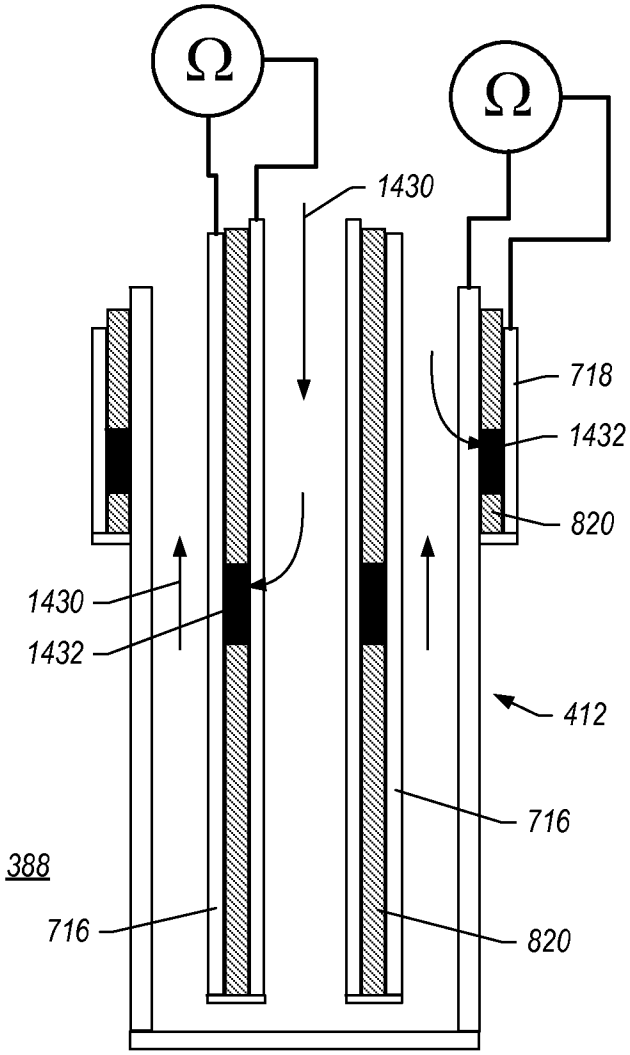


FIG. 197

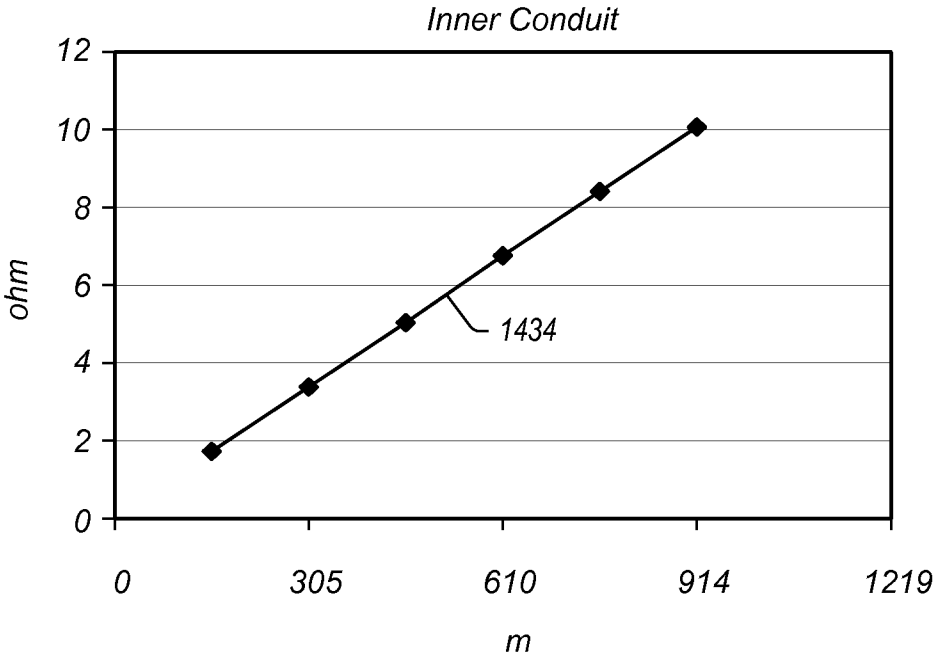


FIG. 198

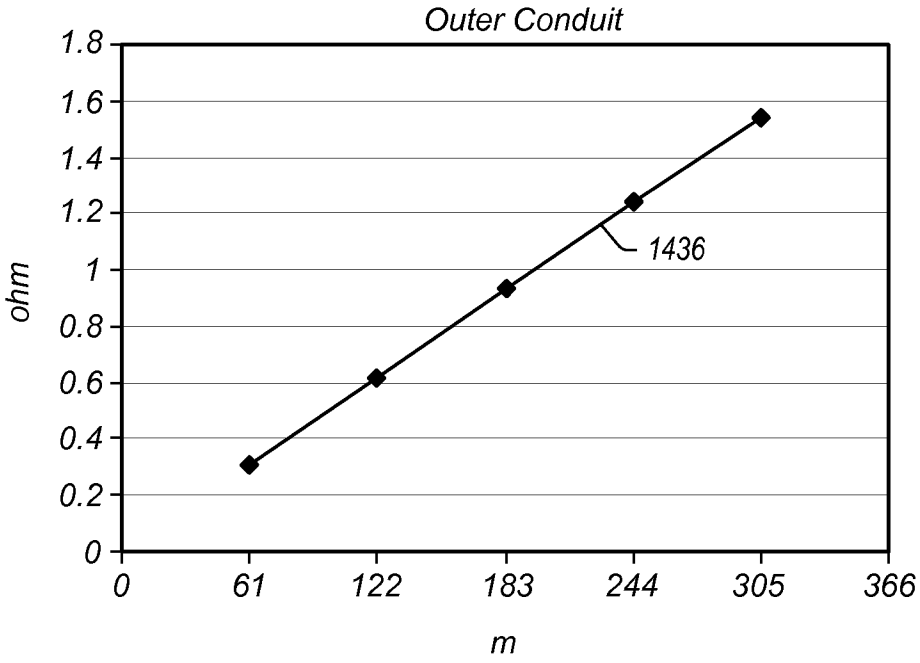


FIG. 199

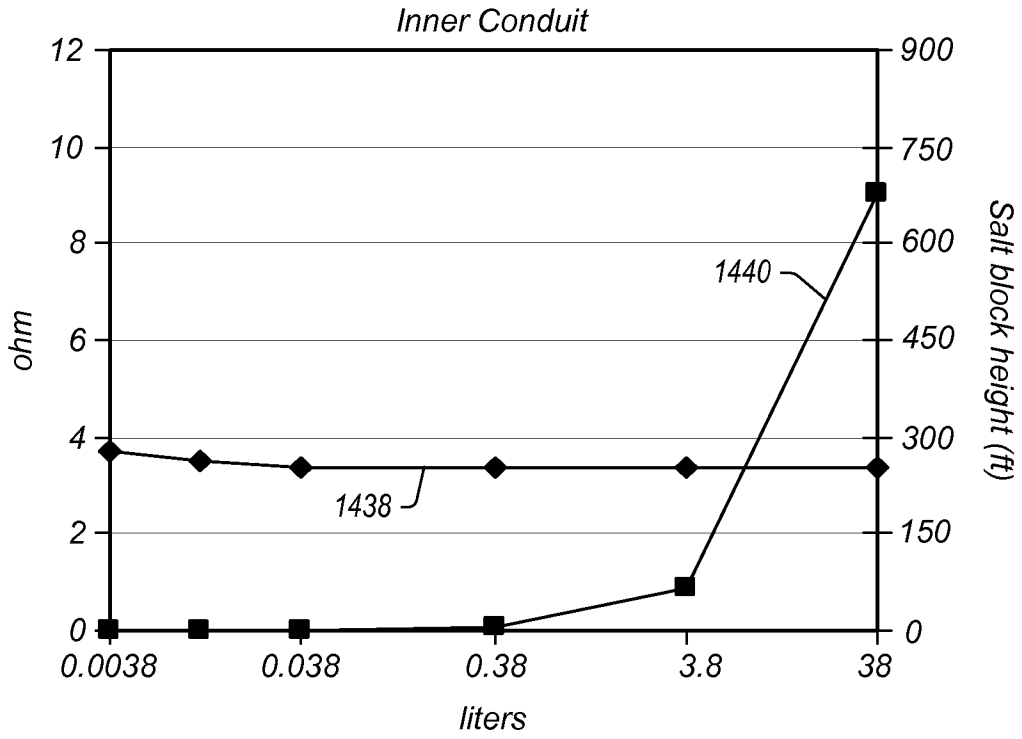


FIG. 200

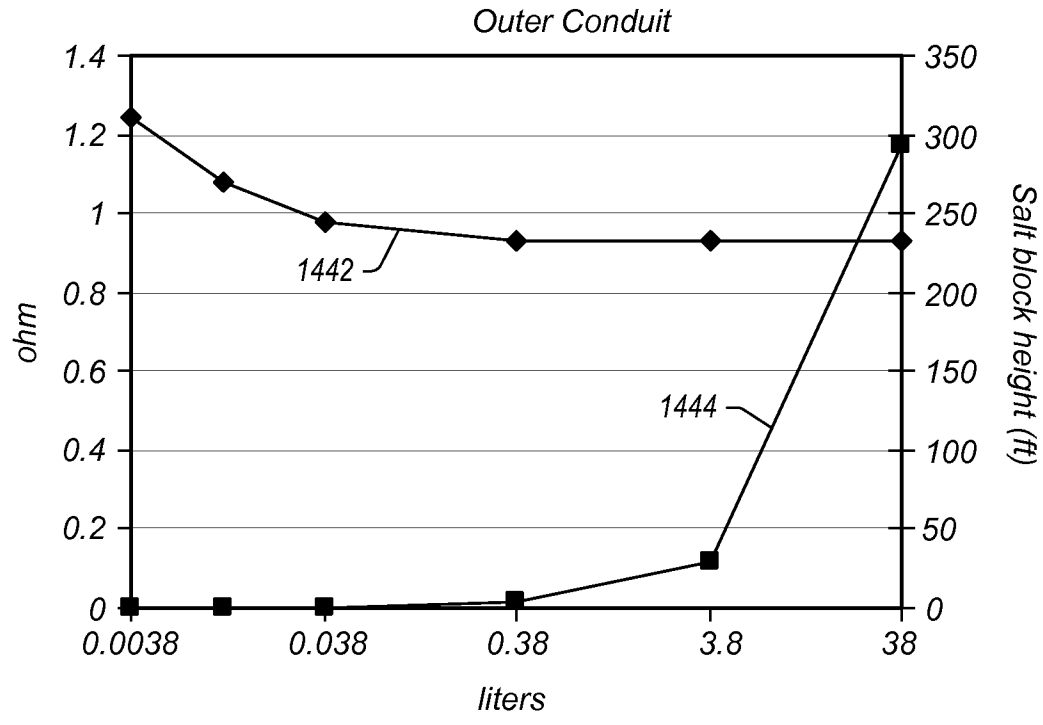


FIG. 201

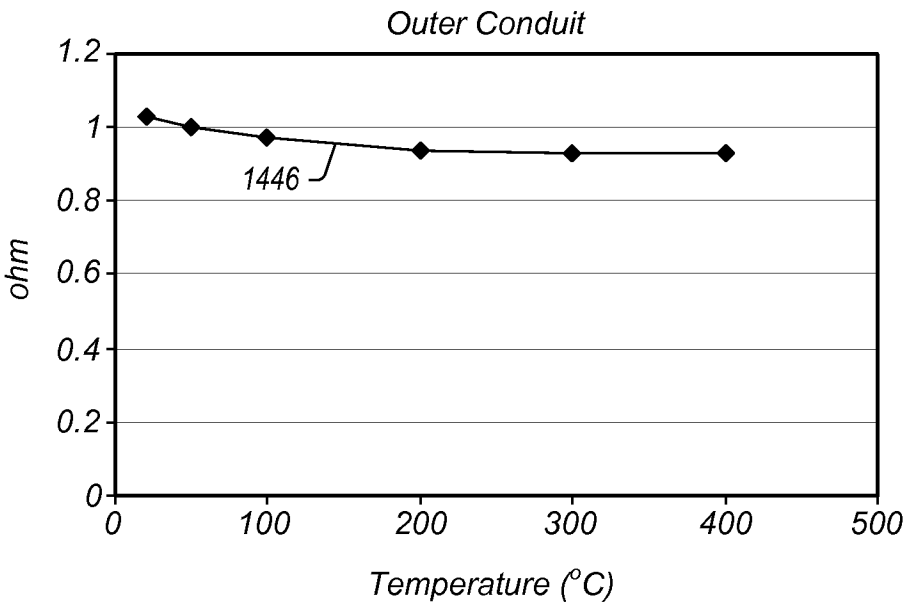


FIG. 202

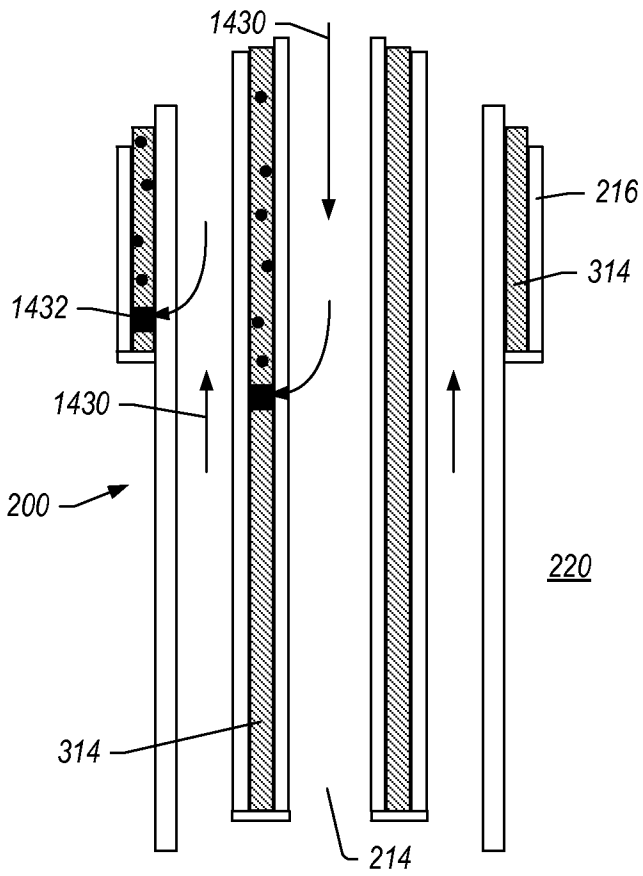


FIG. 203

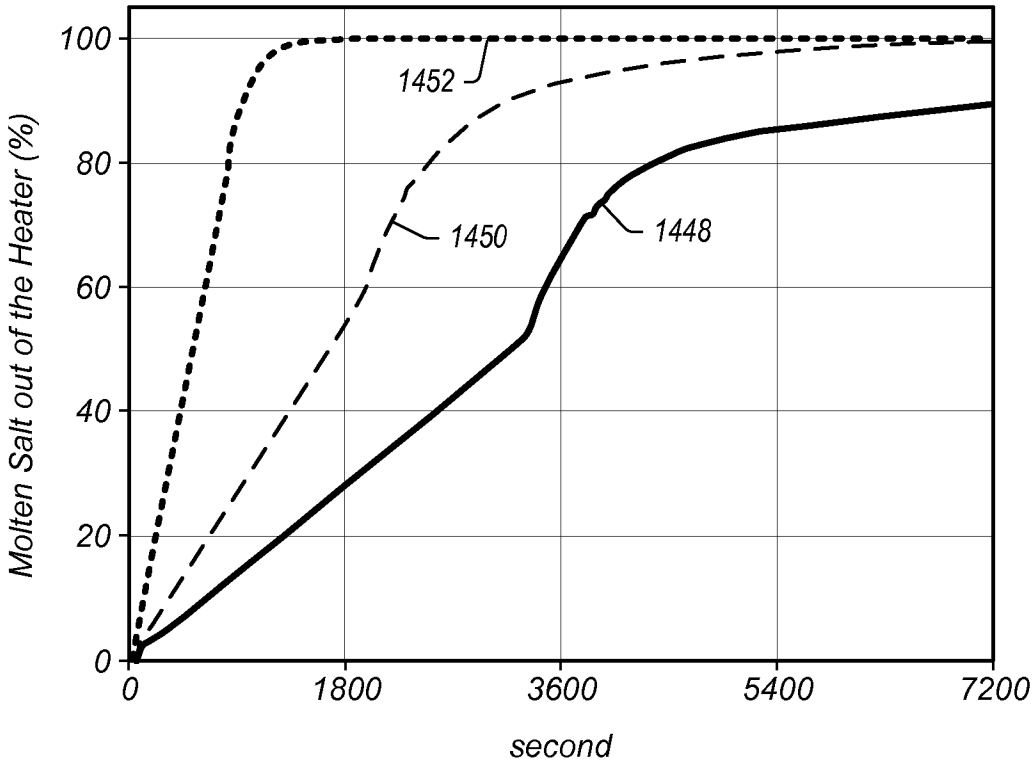


FIG. 204

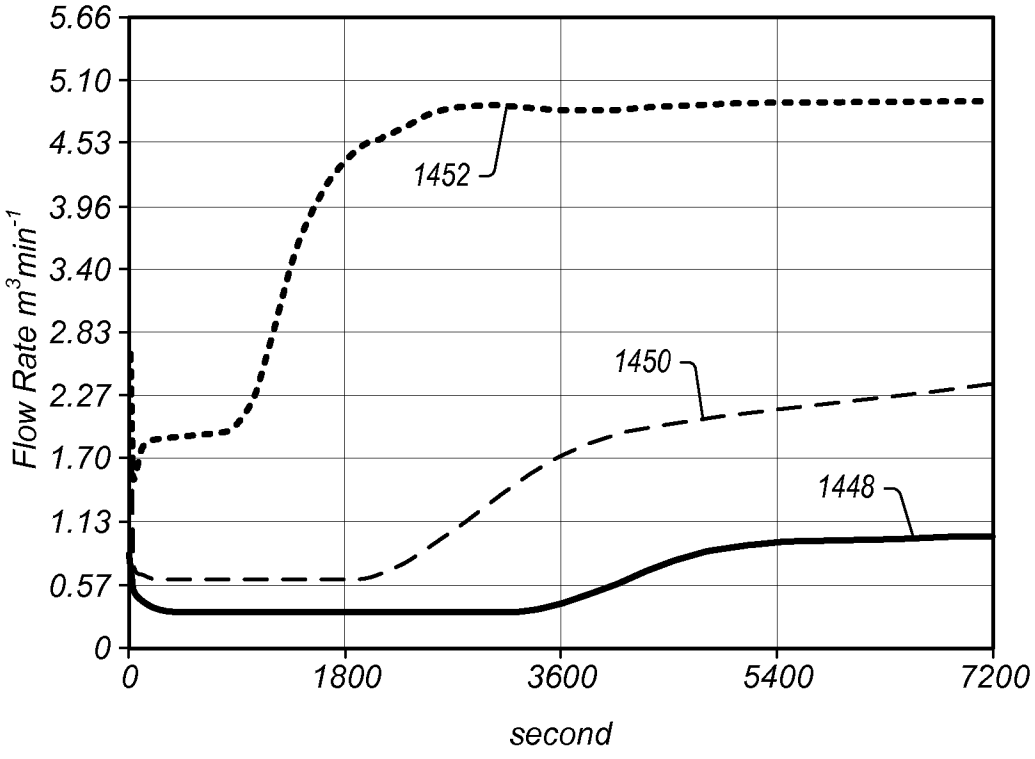


FIG. 205

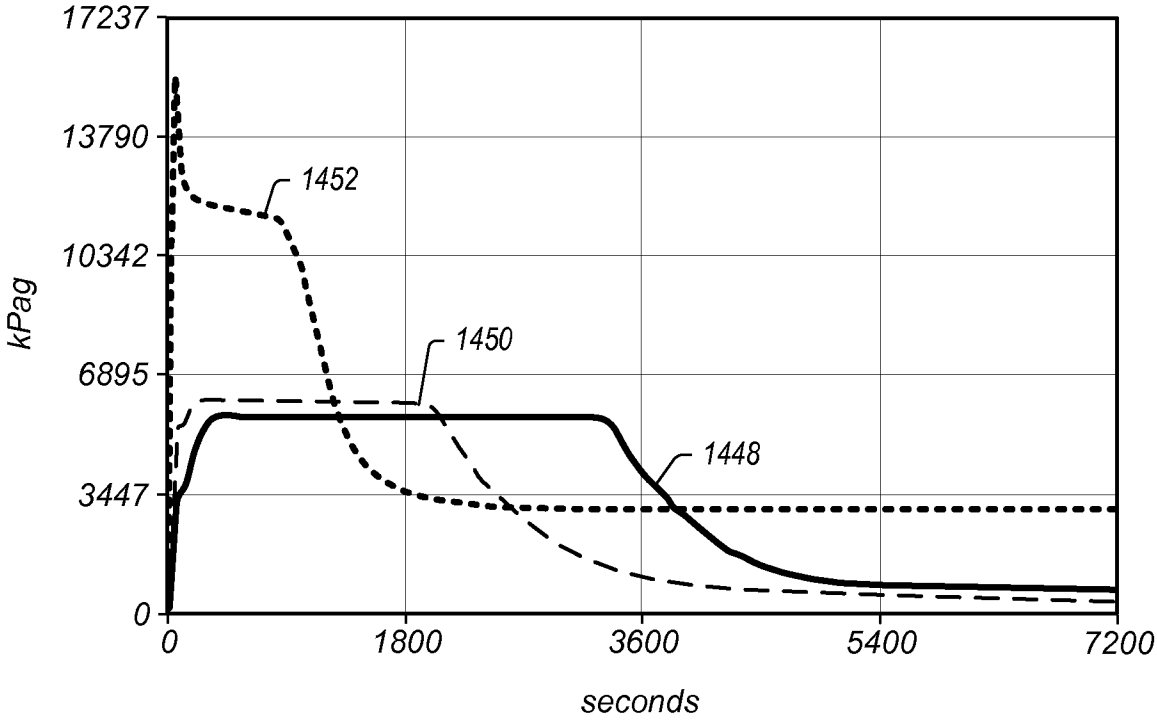


FIG. 206

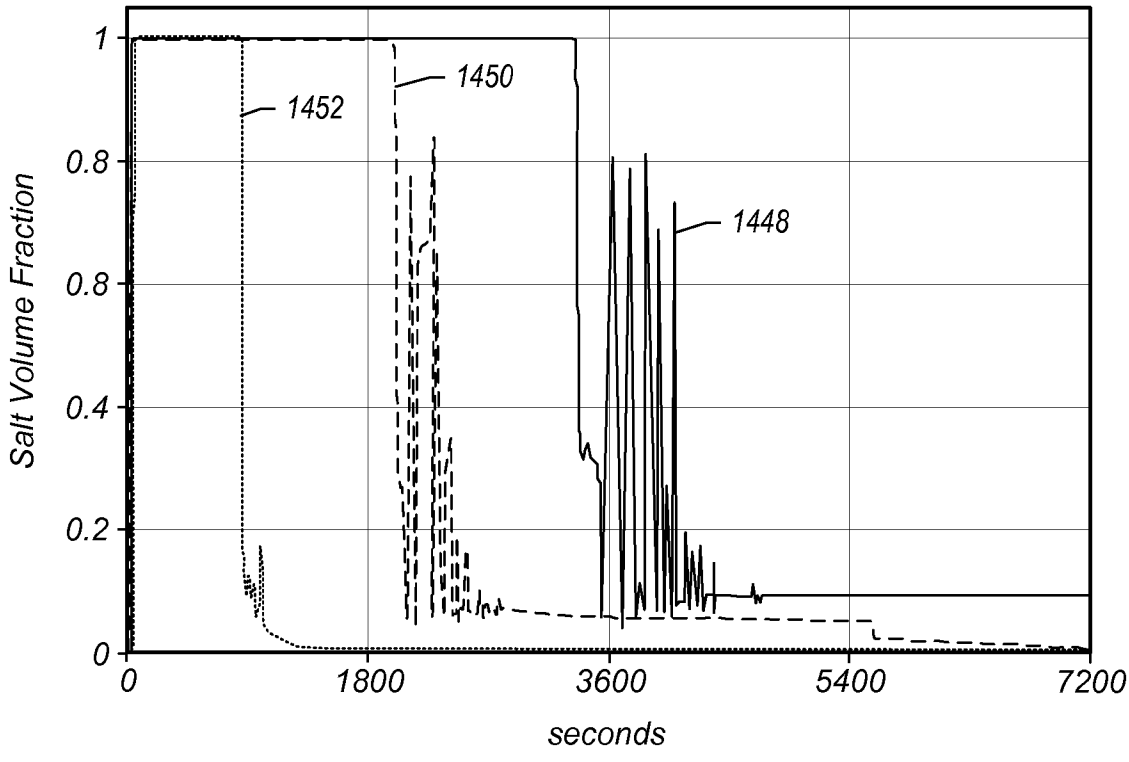


FIG. 207

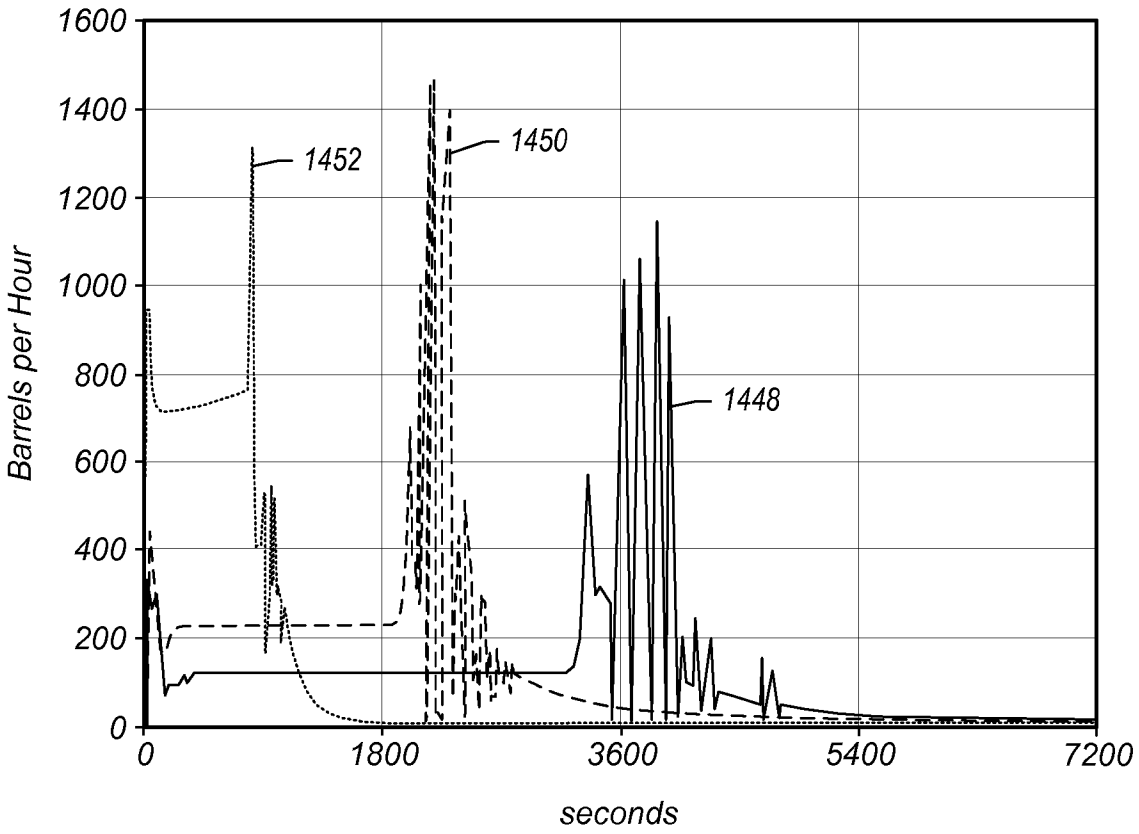

1600
1400
1200
1000
800
600
400
200
0
Barrels per Hour
1452
1450
1448
0
1800
3600
5400
7200
seconds

FIG. 208

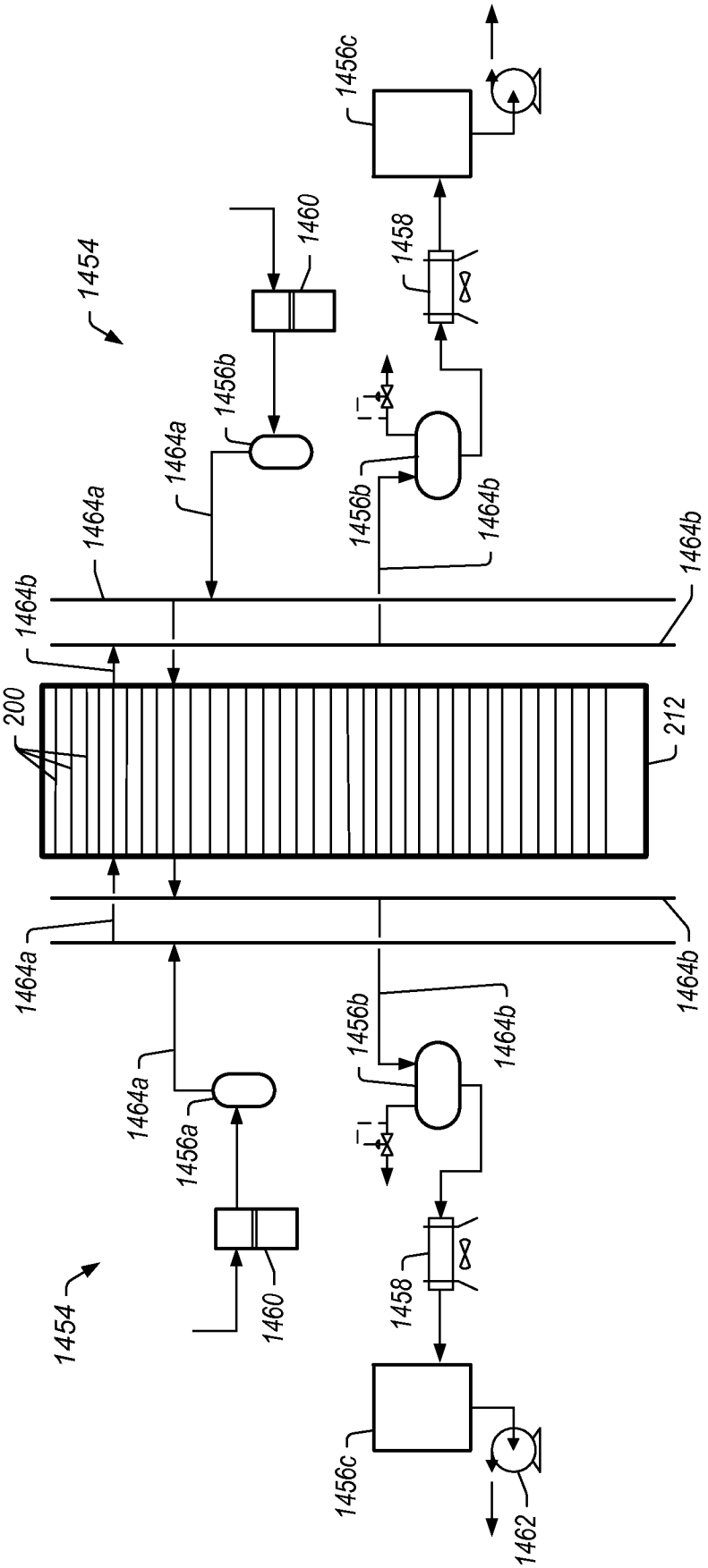


FIG. 209

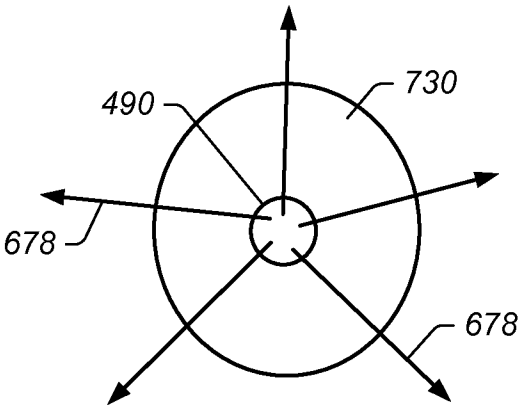


FIG. 210

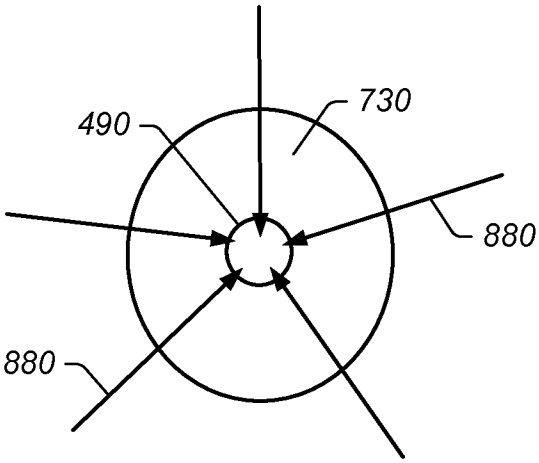


FIG. 211

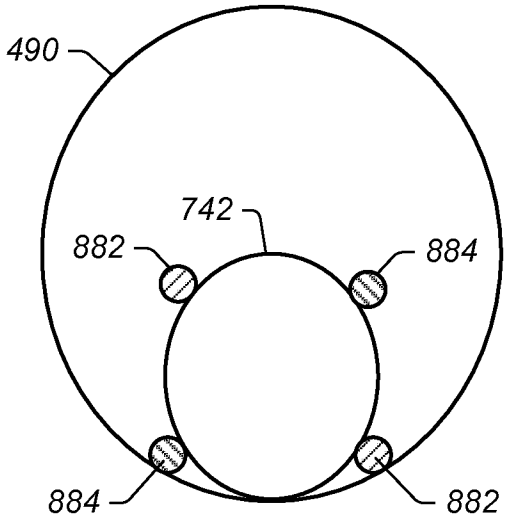


FIG. 212

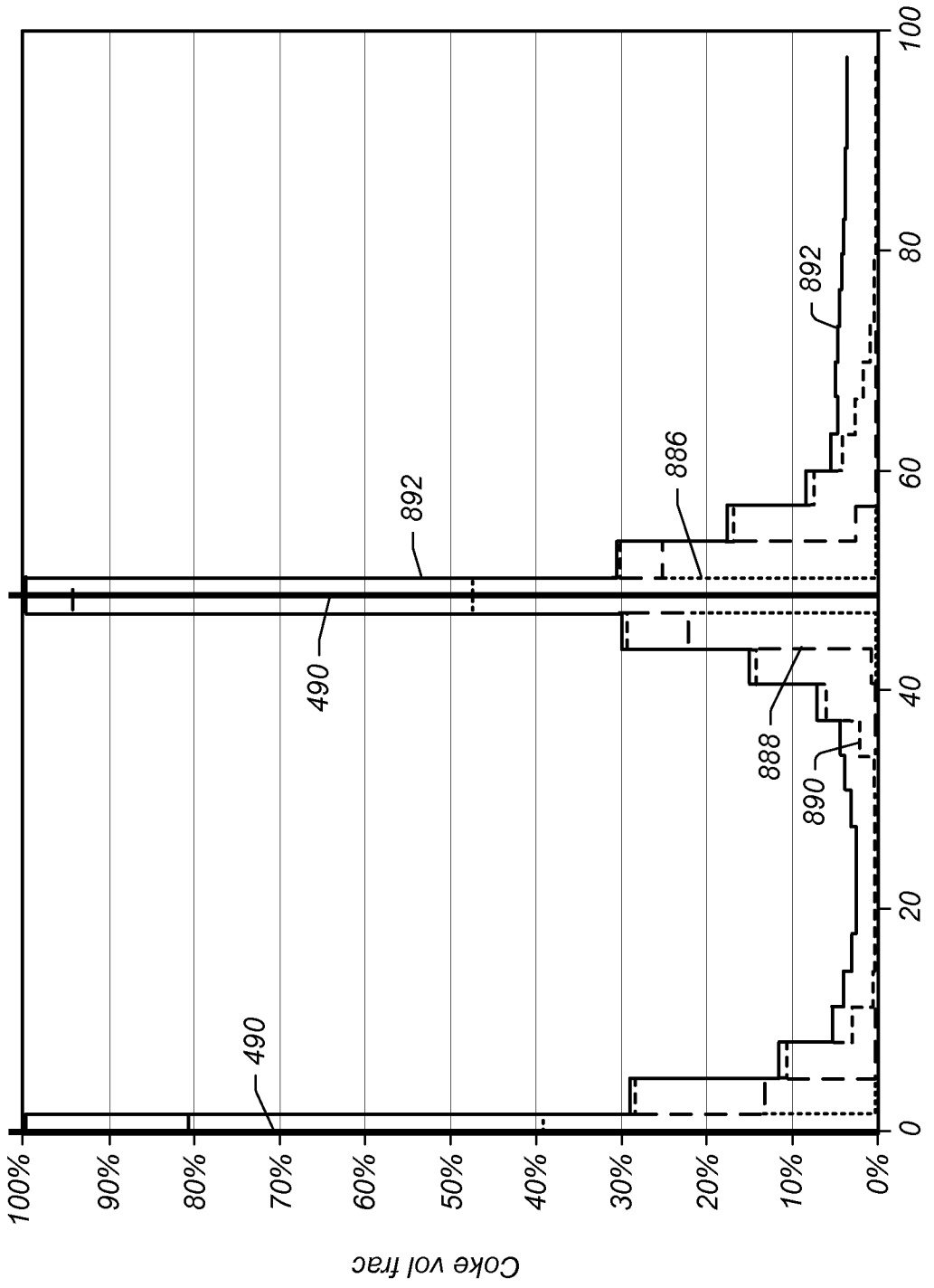

Coke vol frac
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
20
40
60
80
100
Distance (ft)
490
490
892
892
886
888
890

FIG. 213

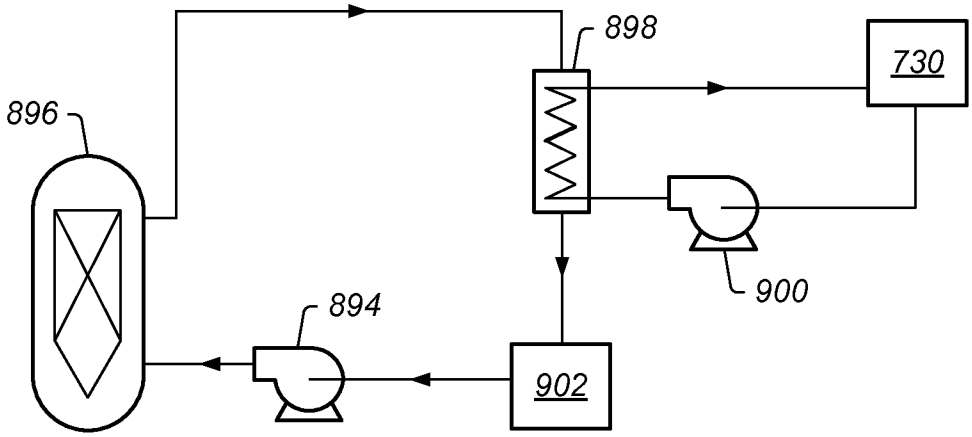


FIG. 214

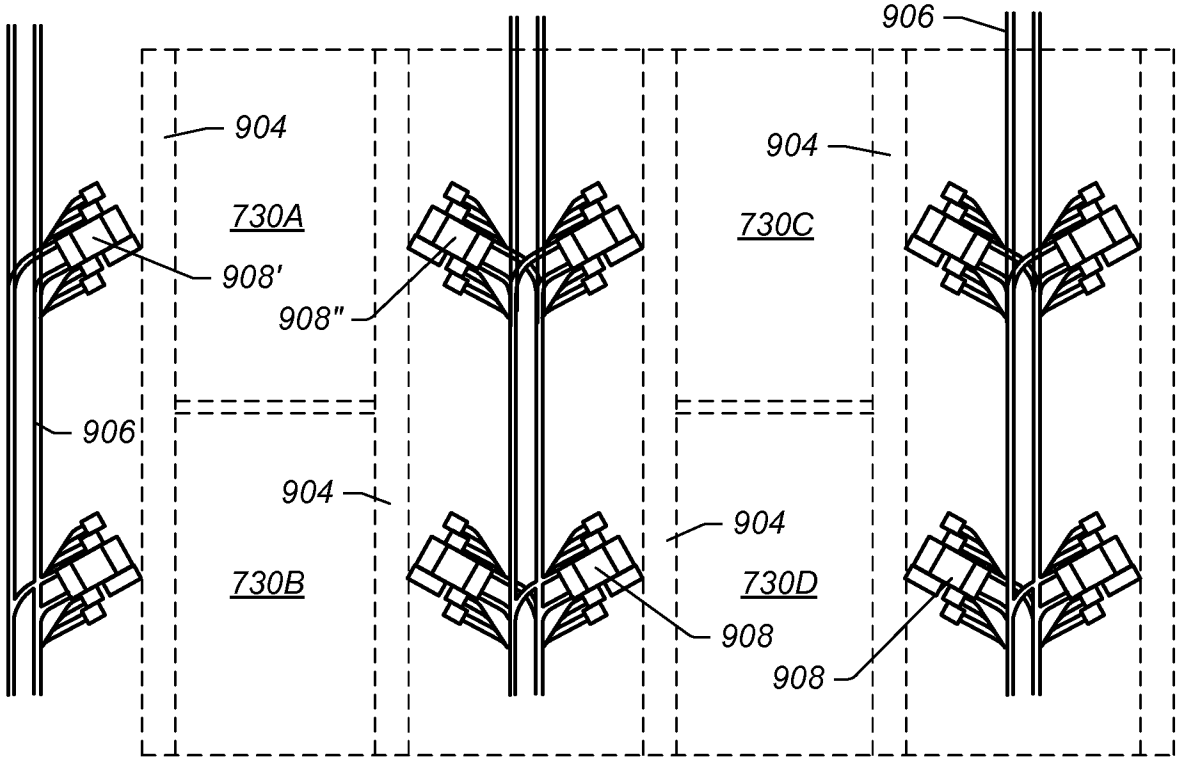


FIG. 215

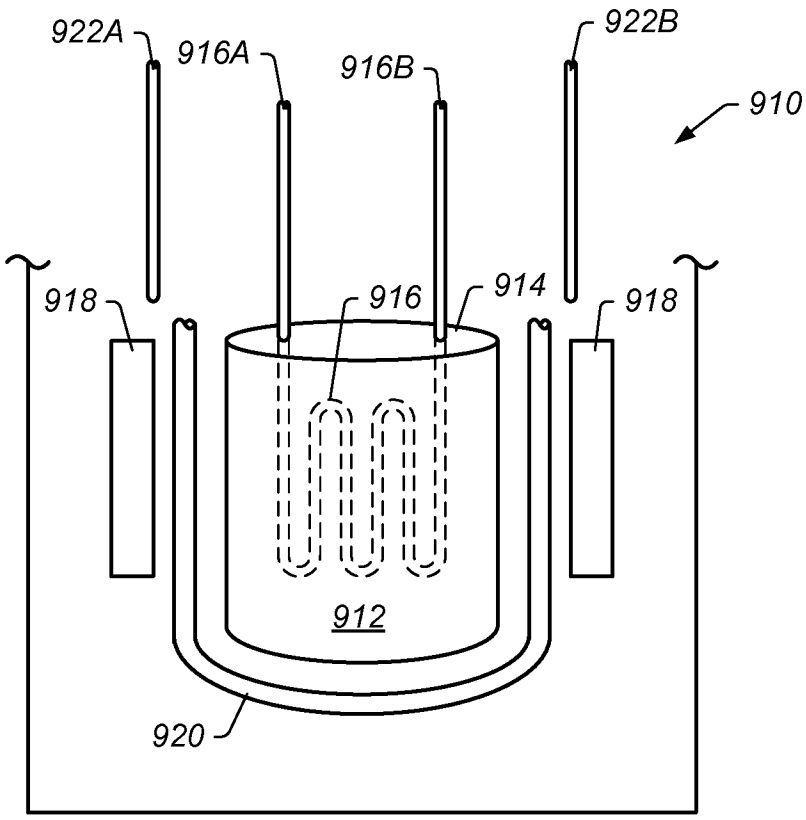


FIG. 216

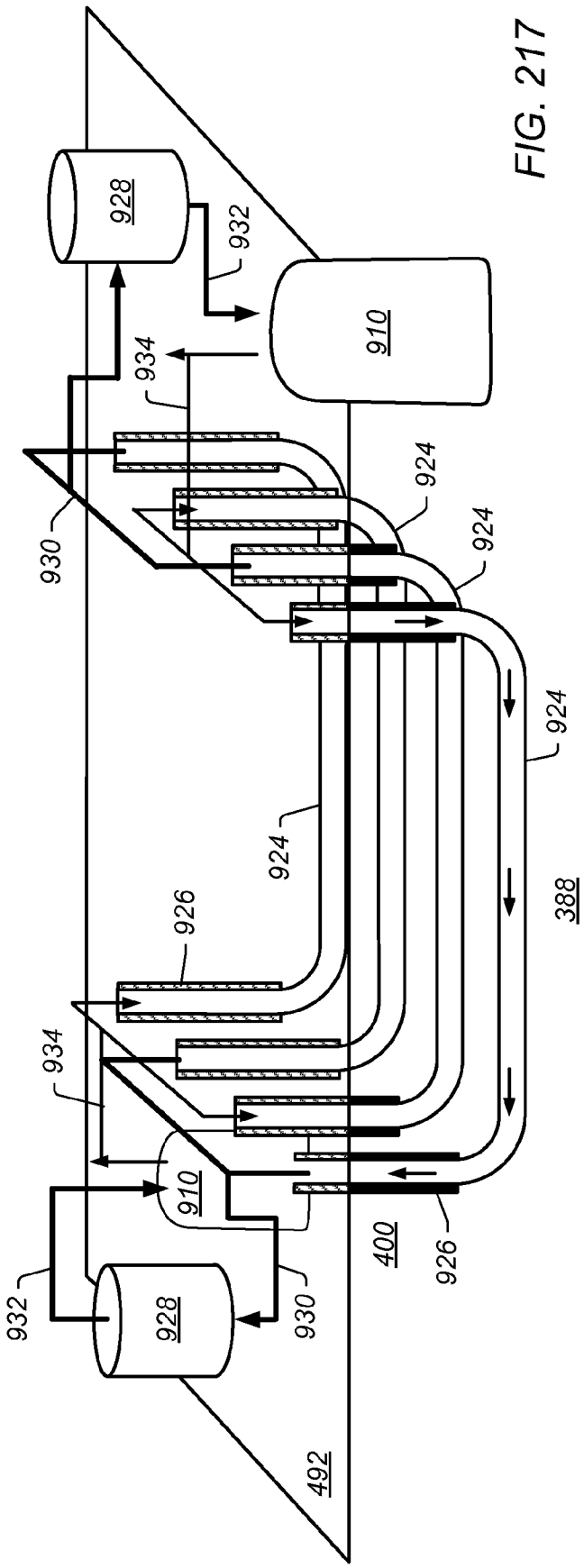

928
932
910
934
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930
924
924
924
926
388
934
910
400
926
932
928
930
492

FIG. 217

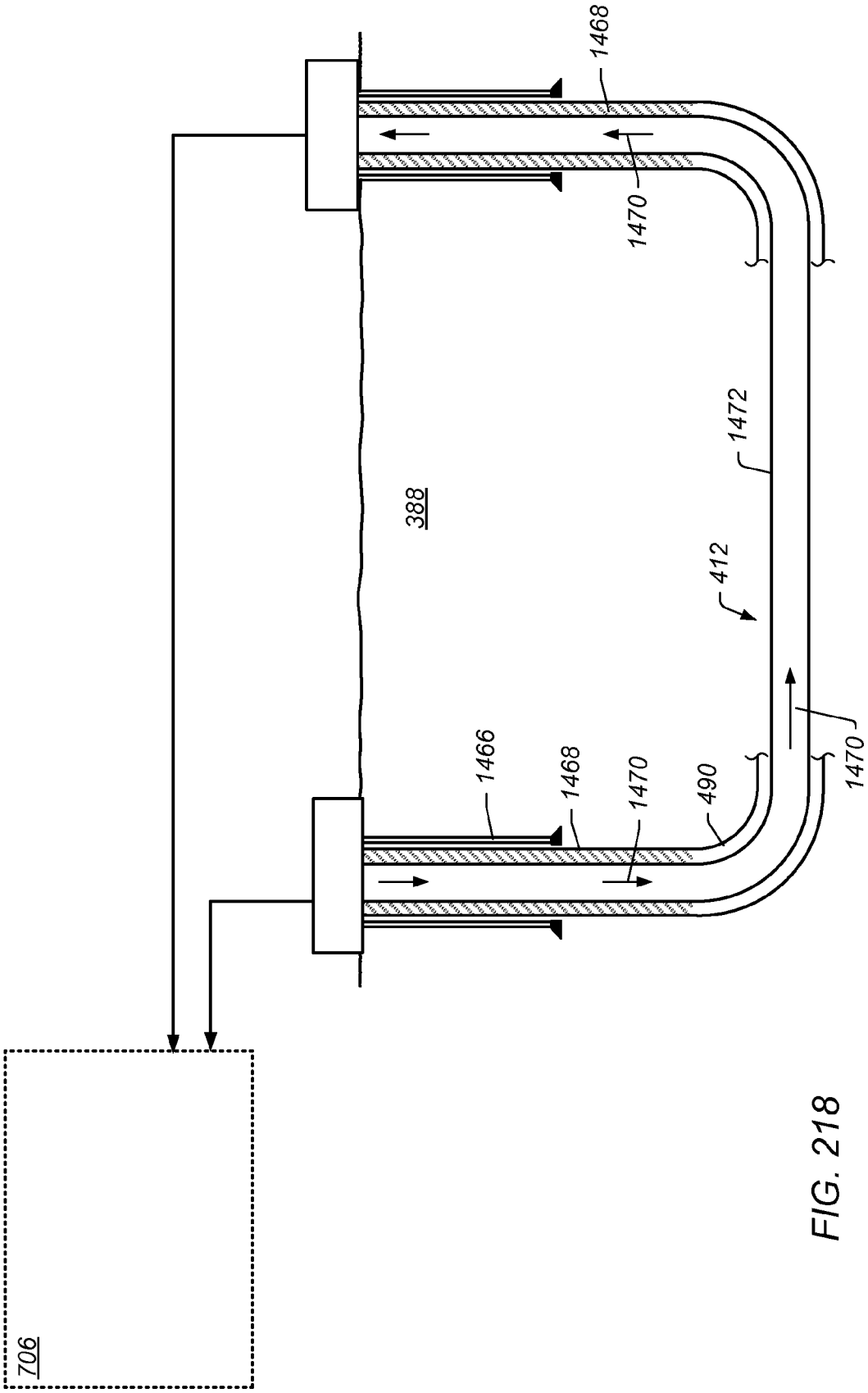


FIG. 218

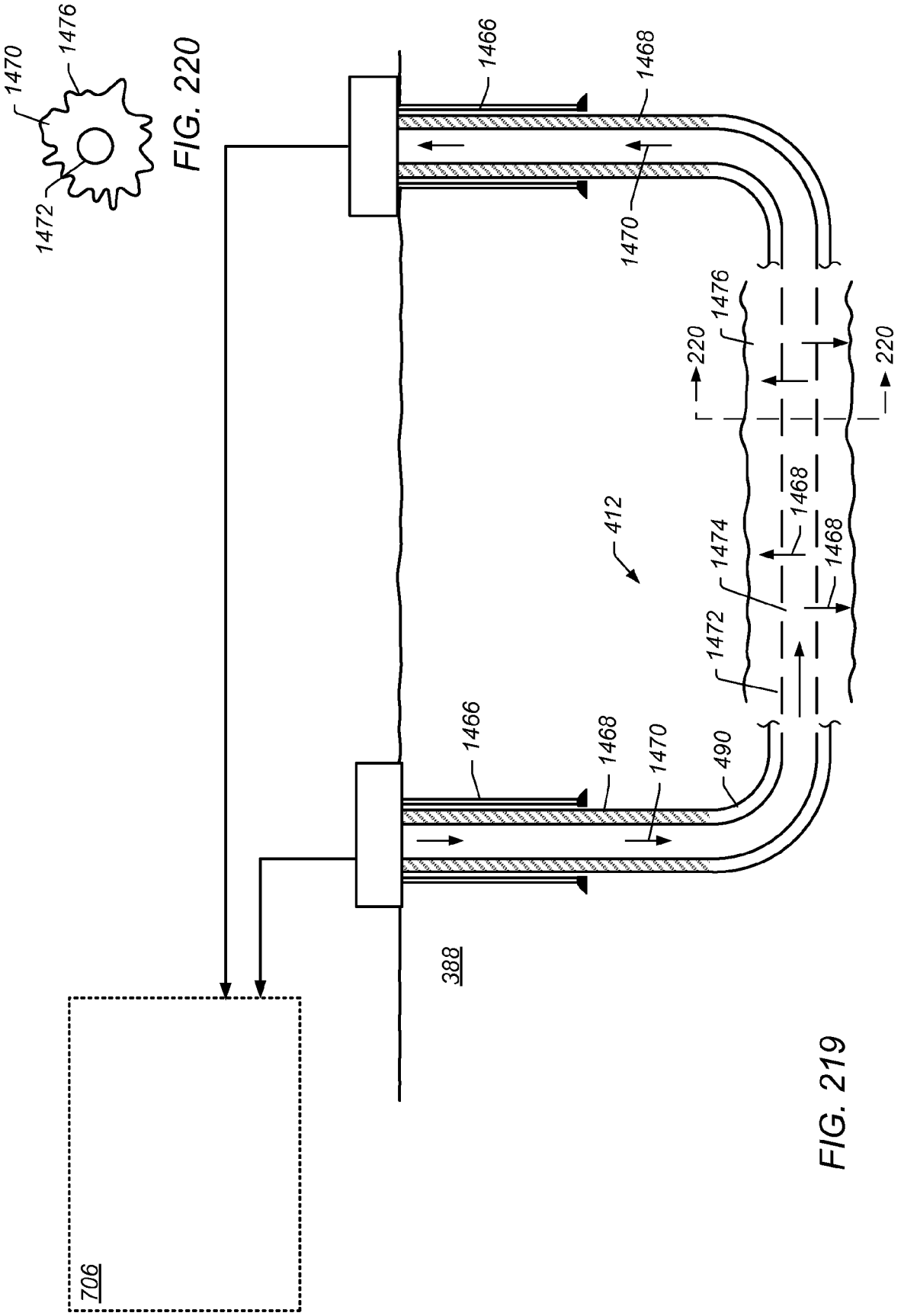


FIG. 220

FIG. 219

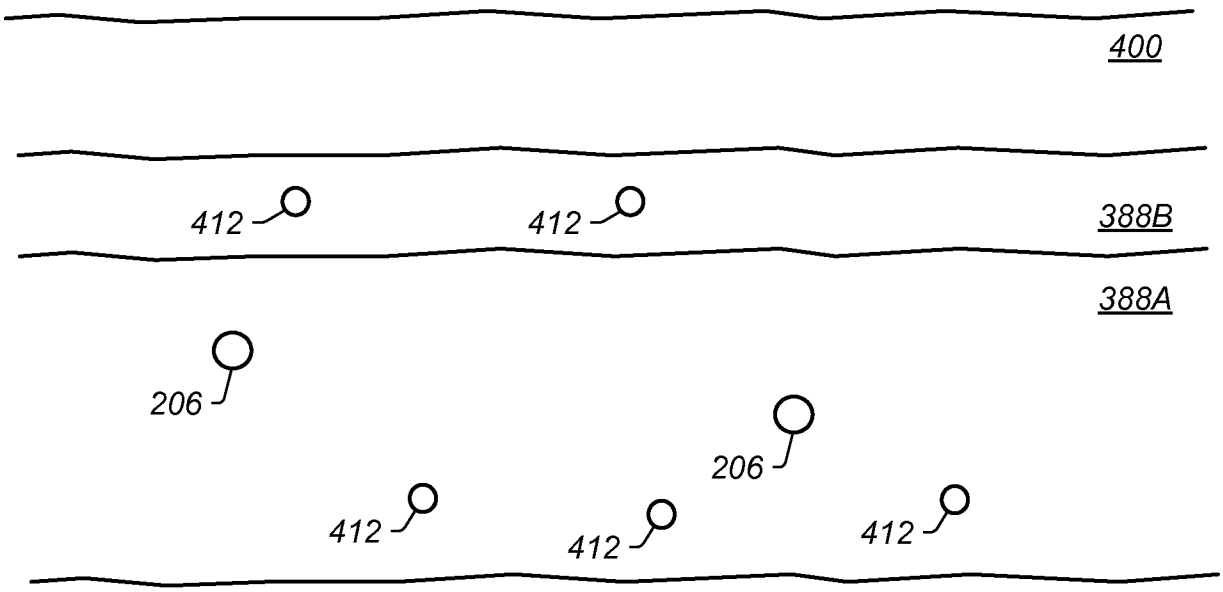


FIG. 221B

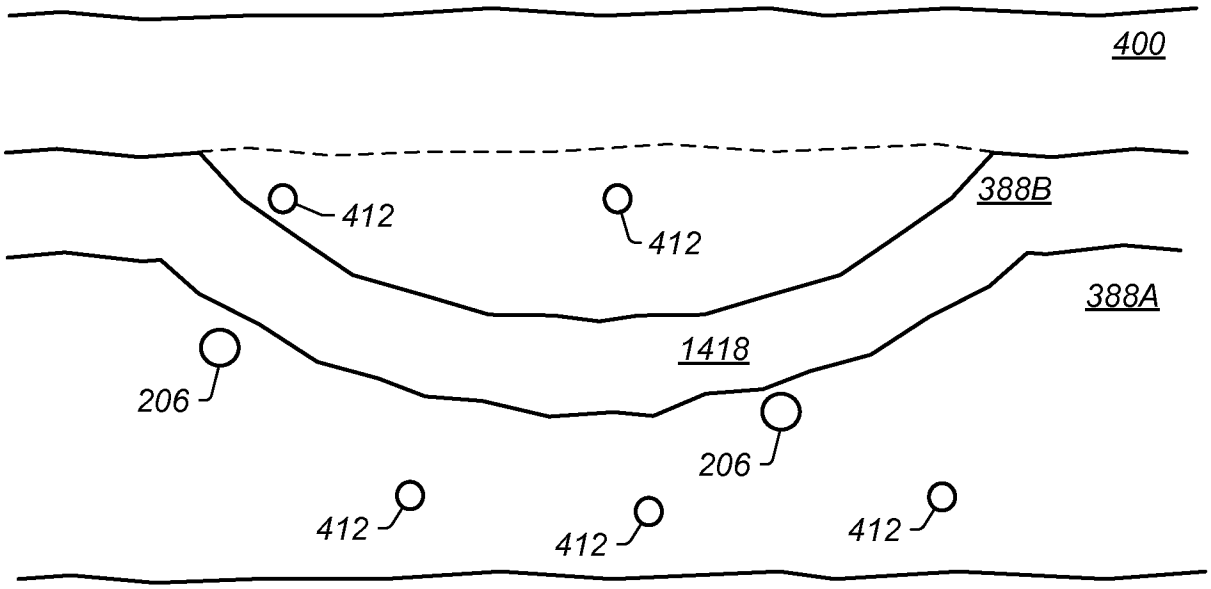


FIG. 221B

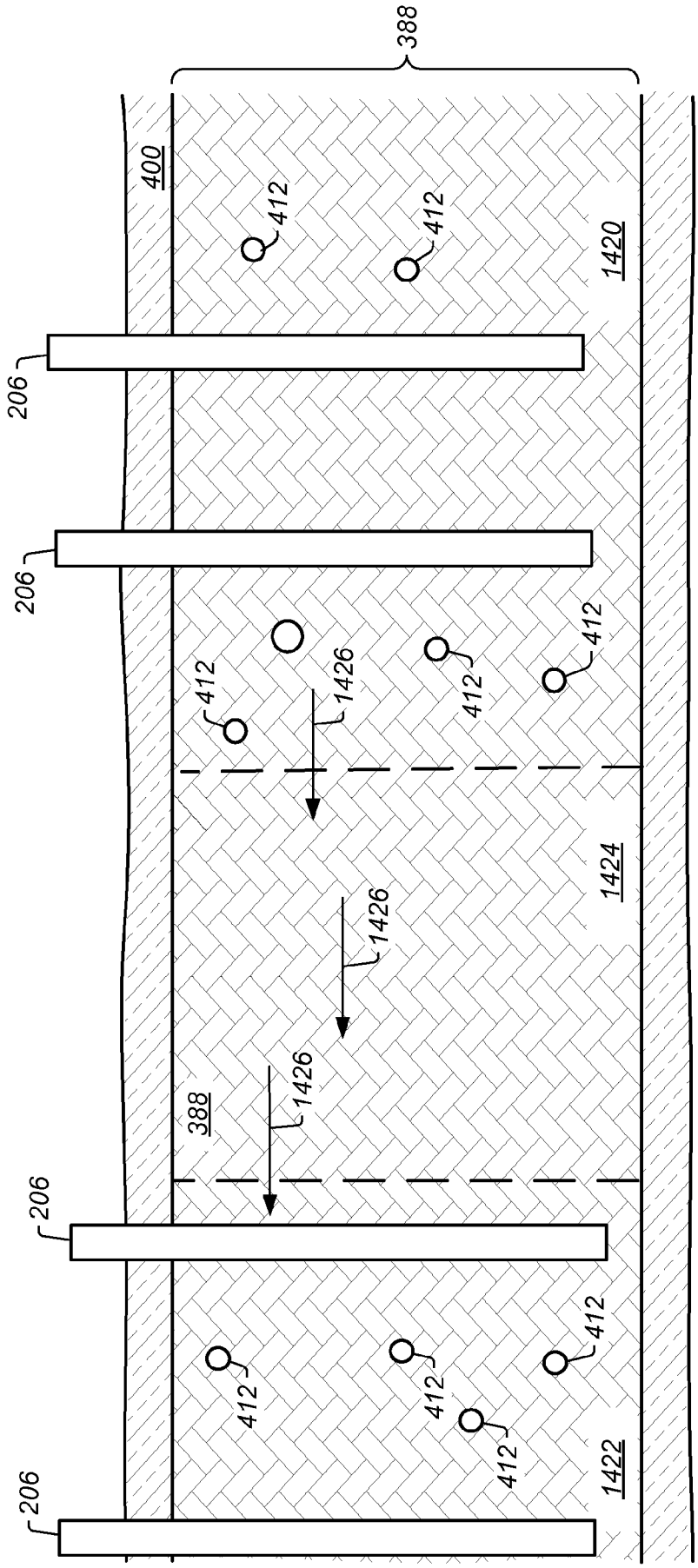

388
400
412
412
1420
206
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412
412
412
1426
1426
1426
1424
388
206
412
412
412
412
1422
206

FIG. 222

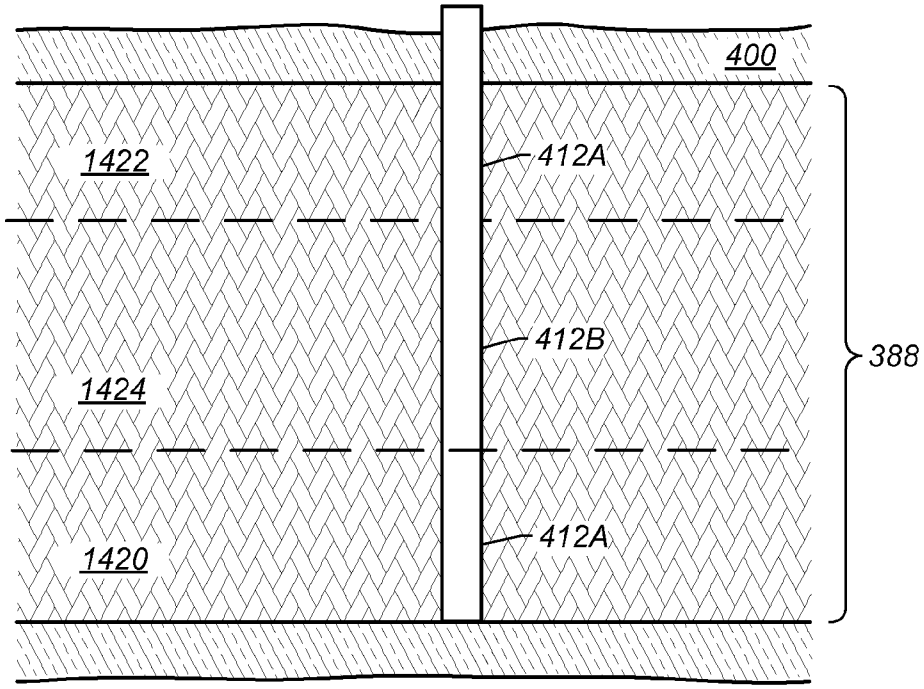


FIG. 223

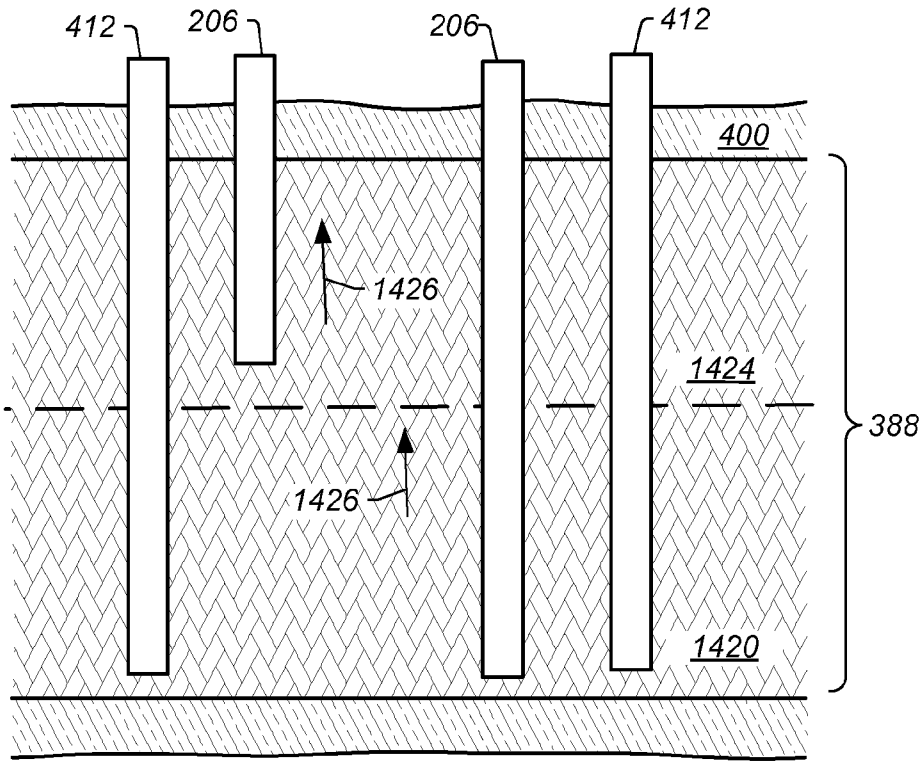


FIG. 224

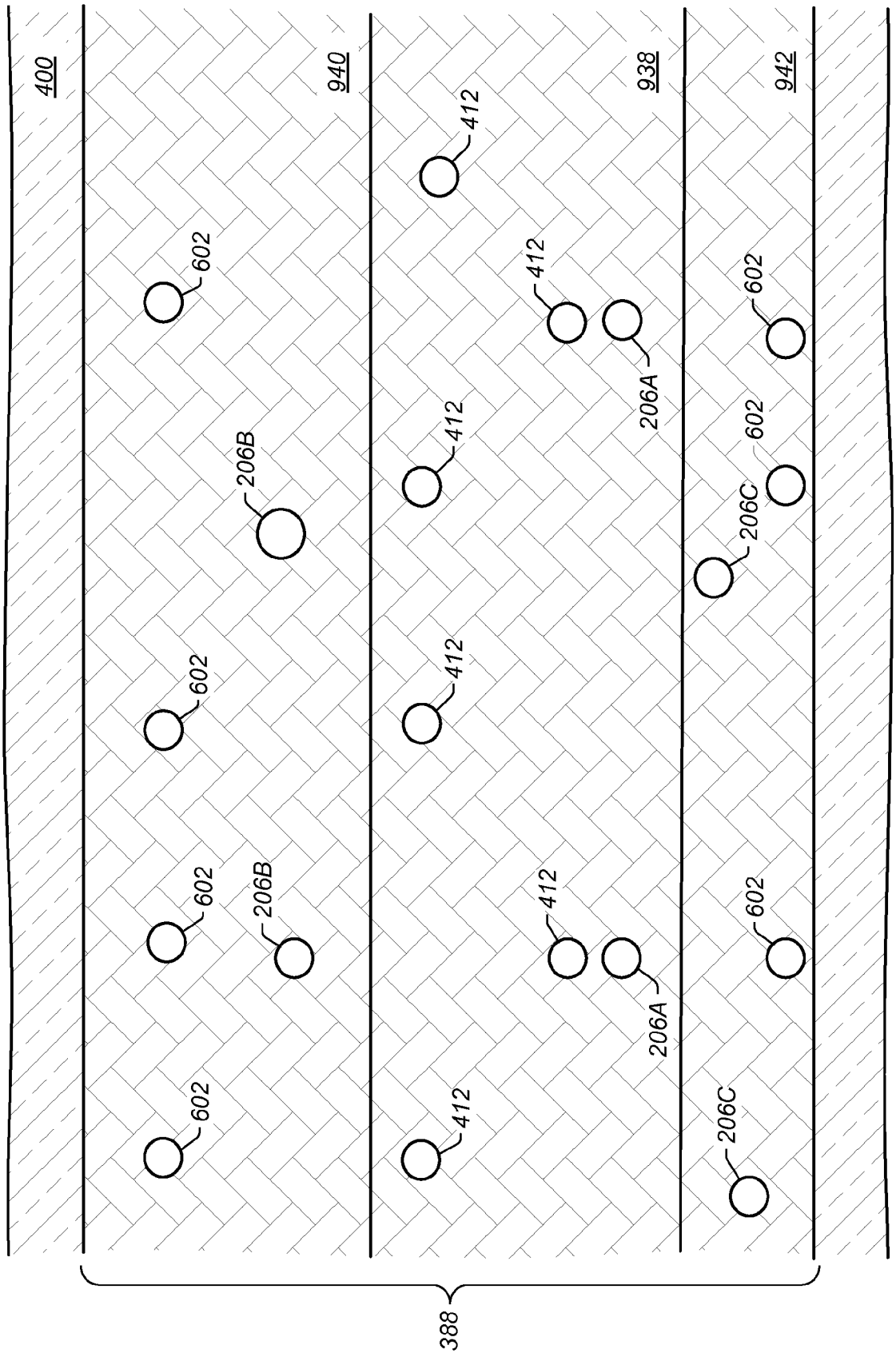


FIG. 225

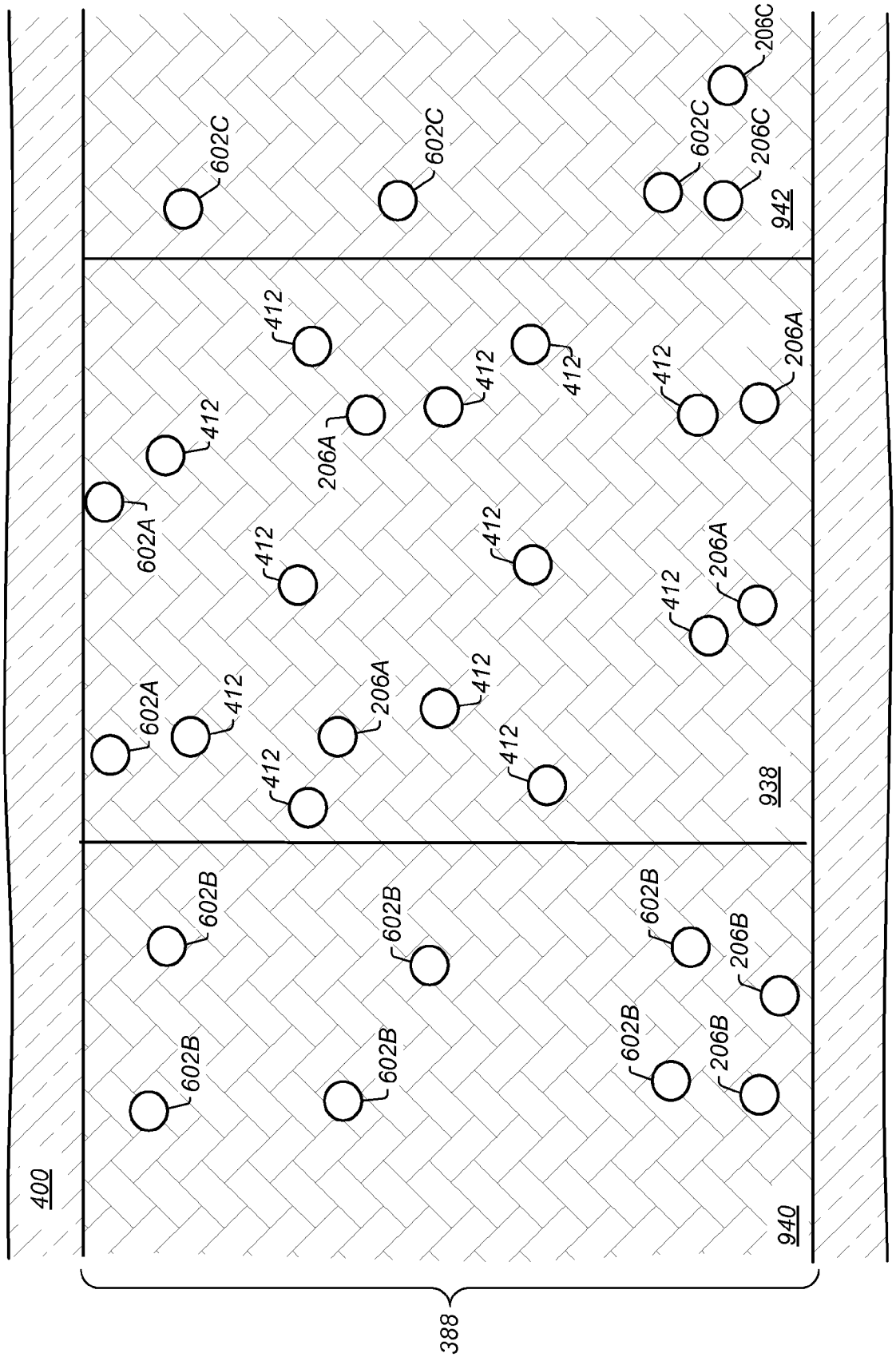

400
602B
602B
602B
602B
602B
602B
206B
206B
940
602A
602A
412
412
412
412
412
412
412
412
206A
206A
206A
938
602C
602C
602C
206C
206C
942
388

FIG. 226

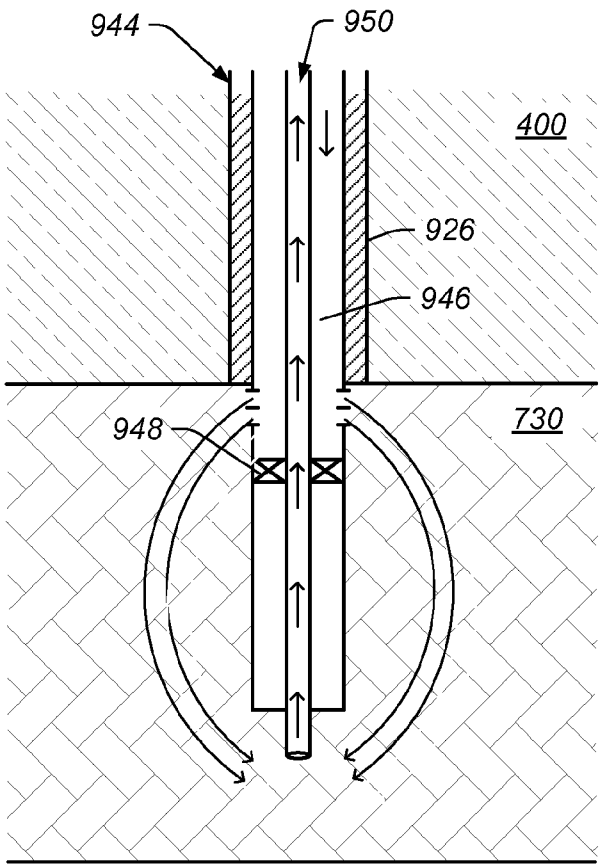


FIG. 227

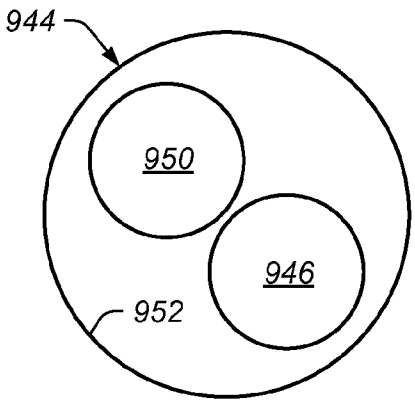


FIG. 228

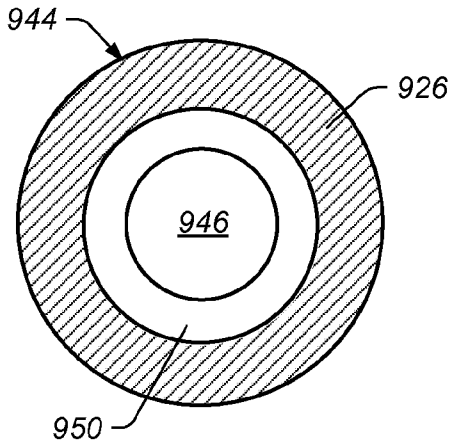


FIG. 229

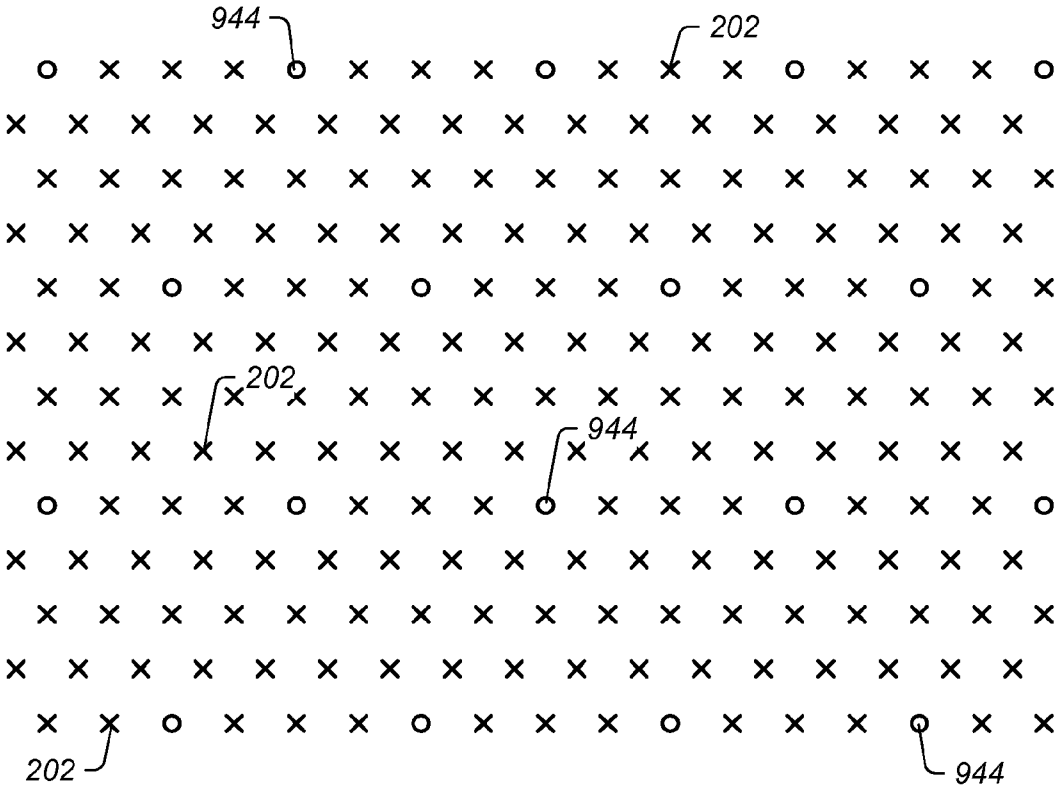


FIG. 230

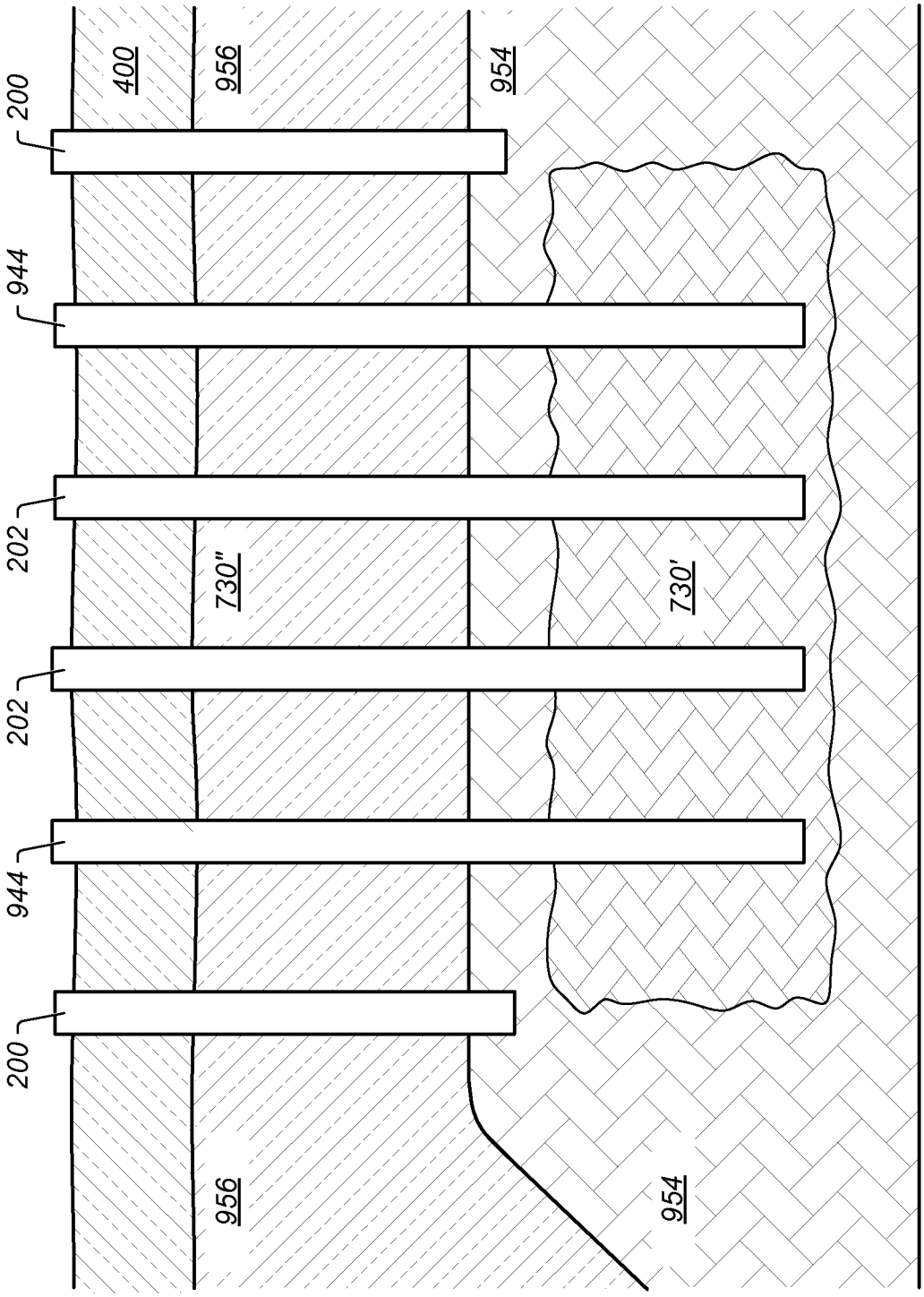


FIG. 231

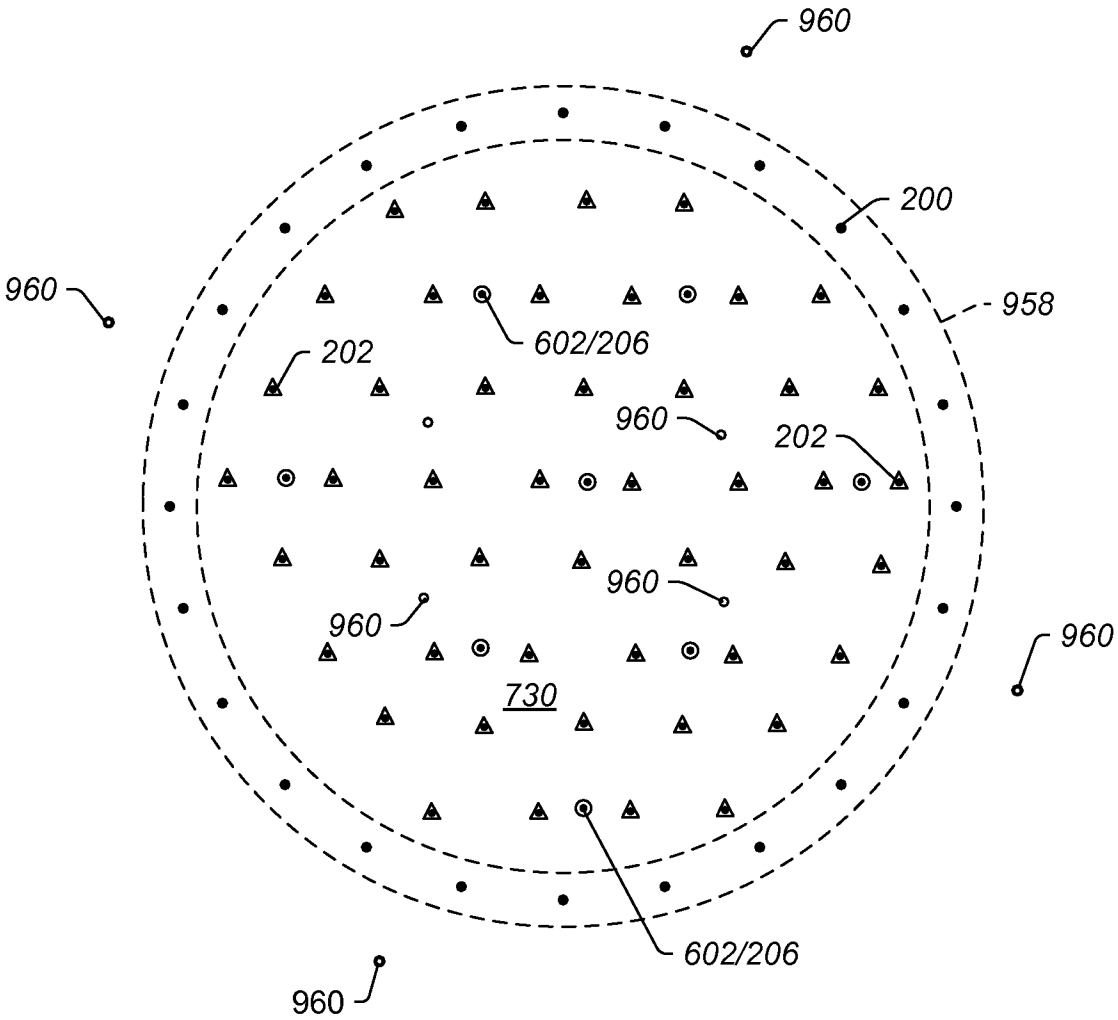


FIG. 232

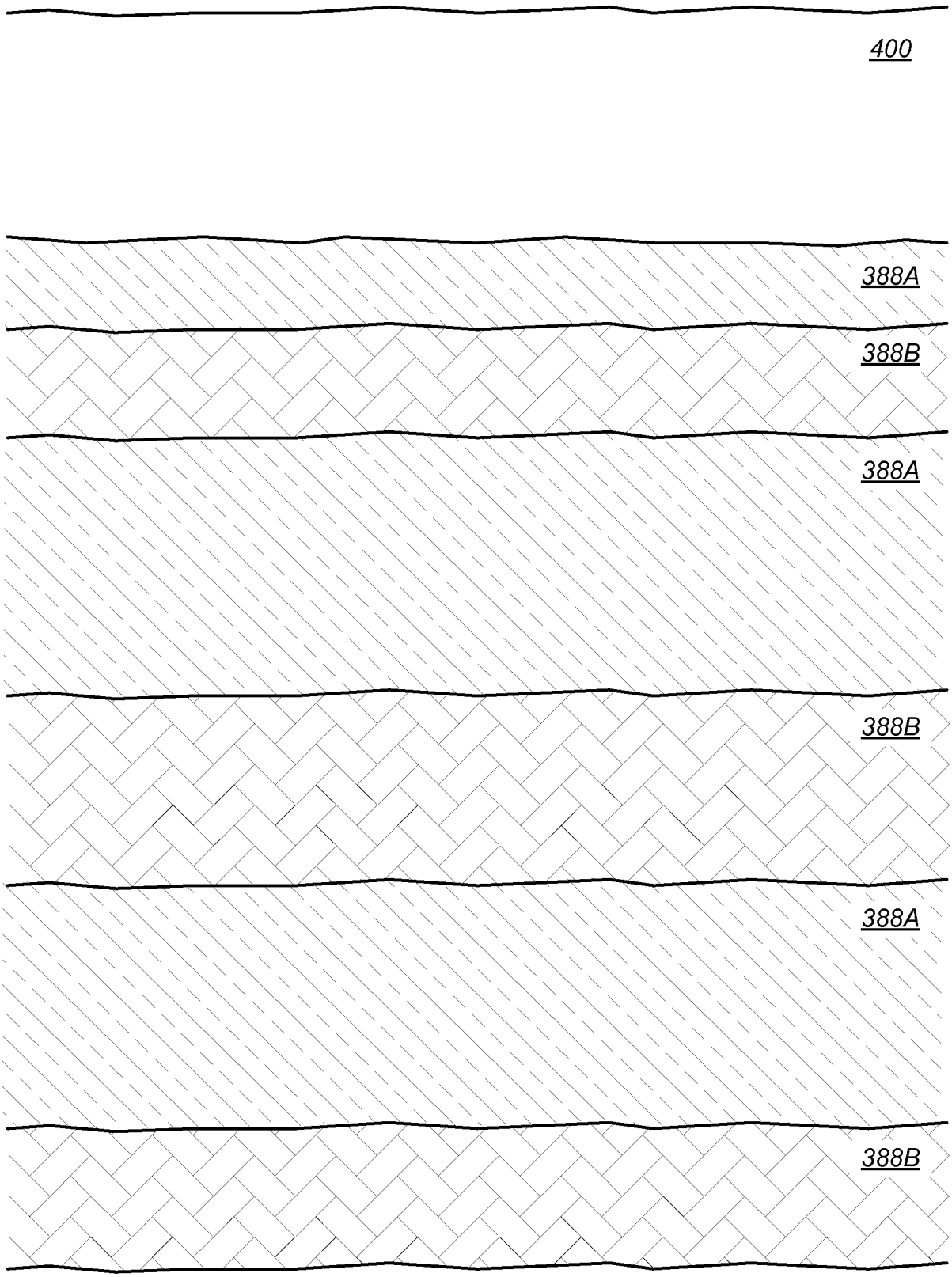


FIG. 233

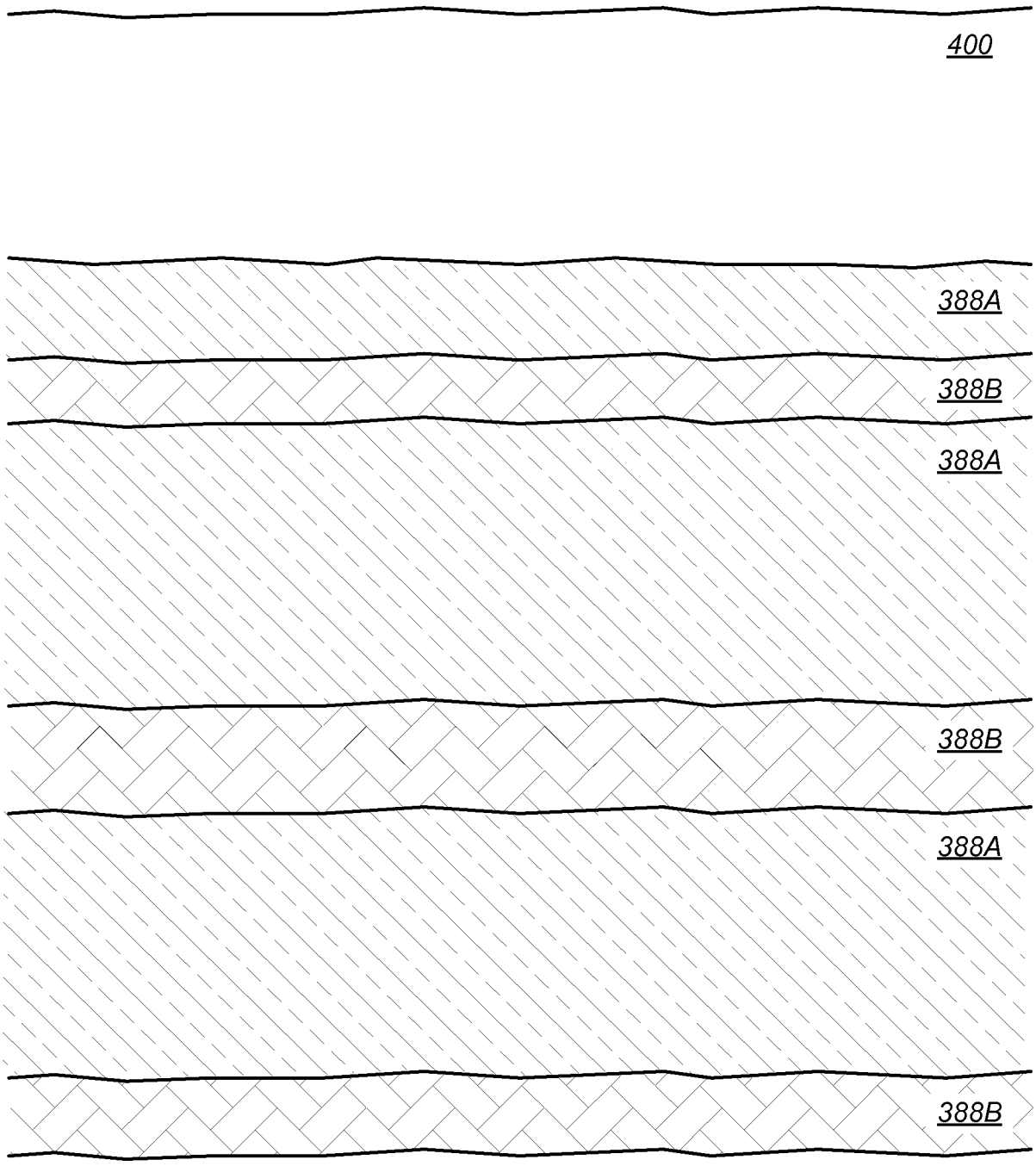
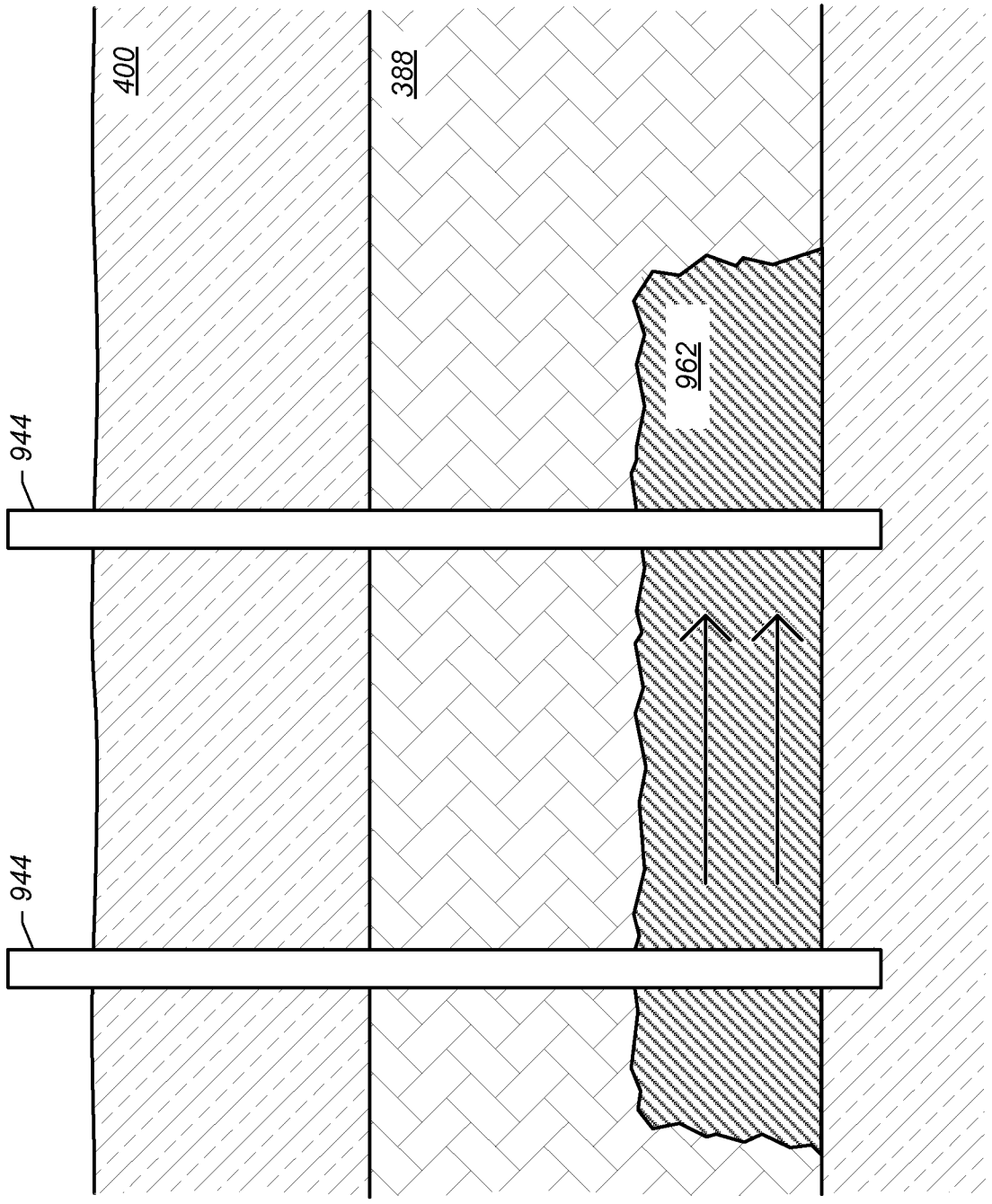


FIG. 234

FIG. 235



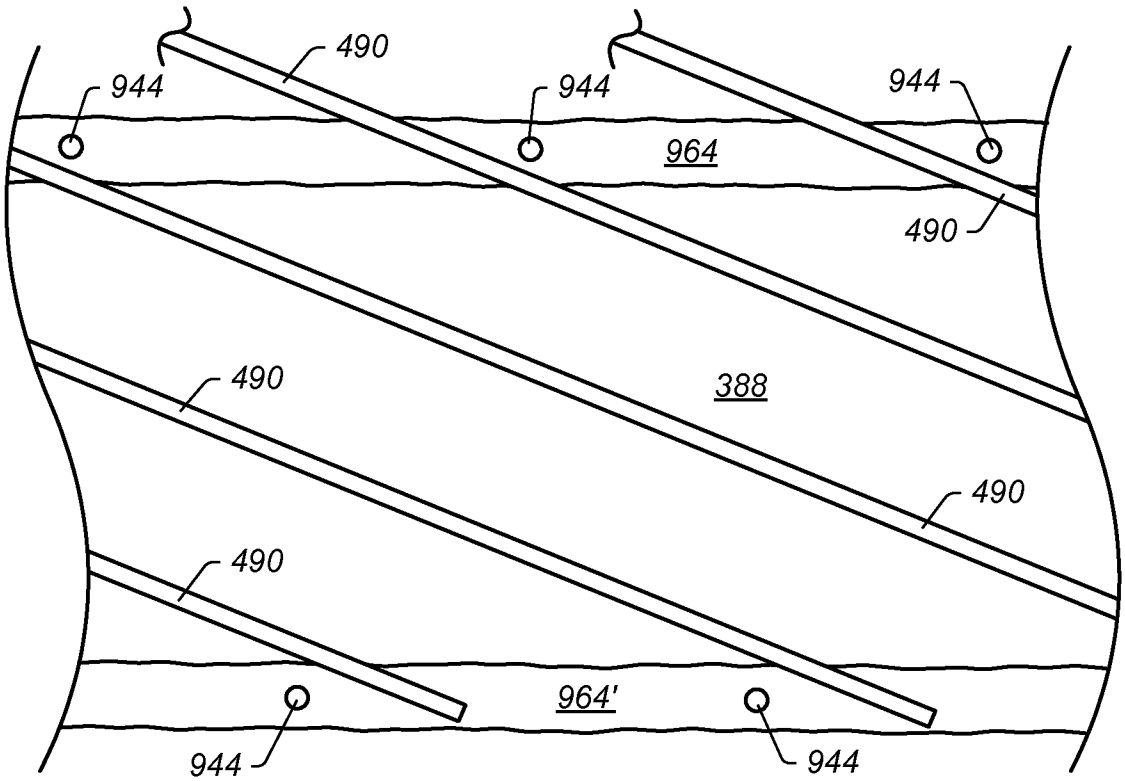


FIG. 236

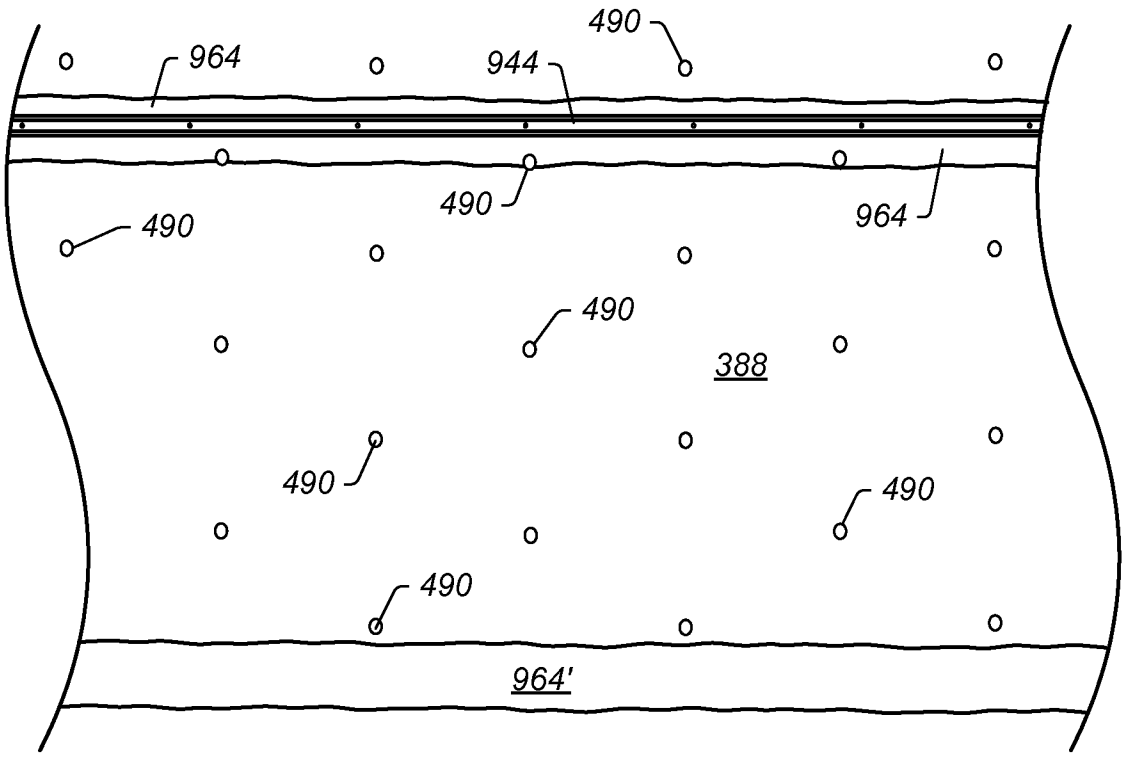


FIG. 237

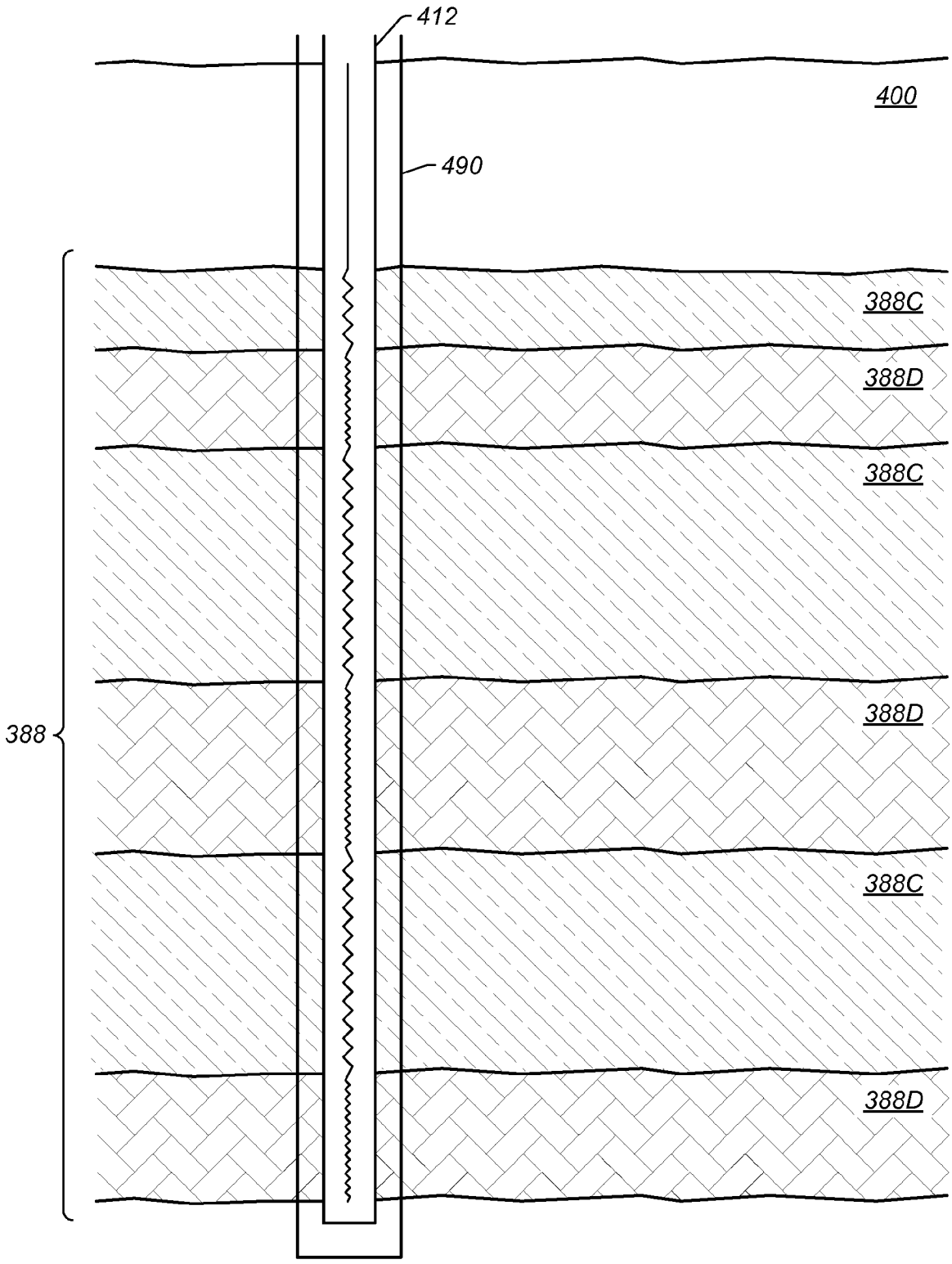


FIG. 238

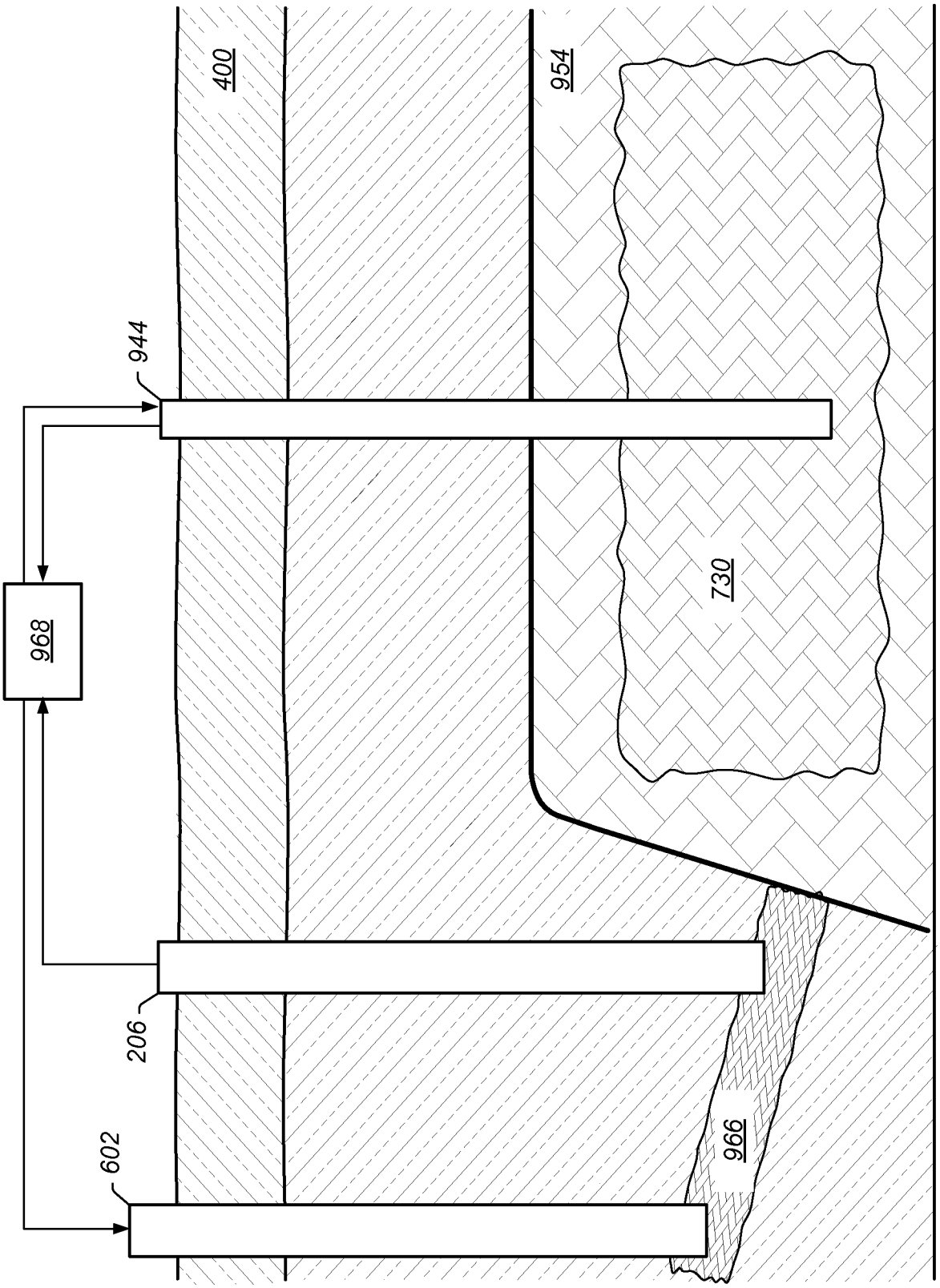


FIG. 239

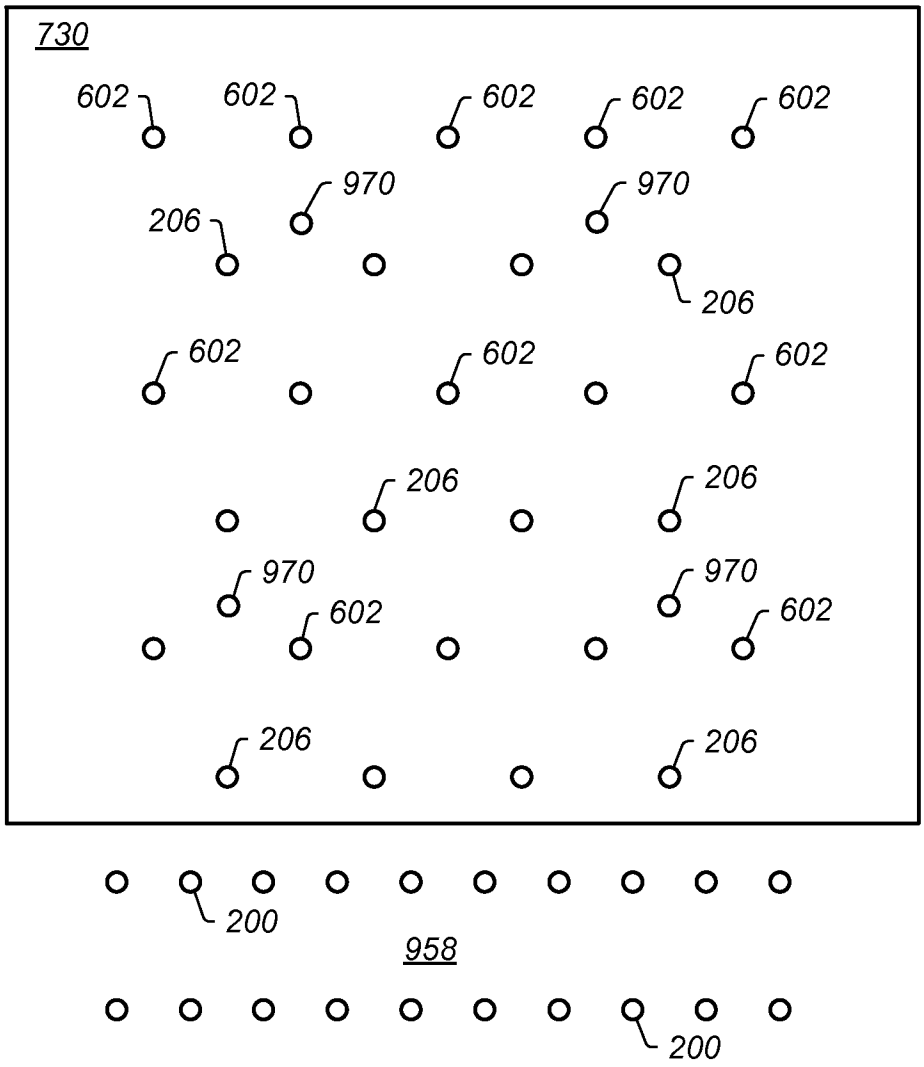

730
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970
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200
958
200

FIG. 240

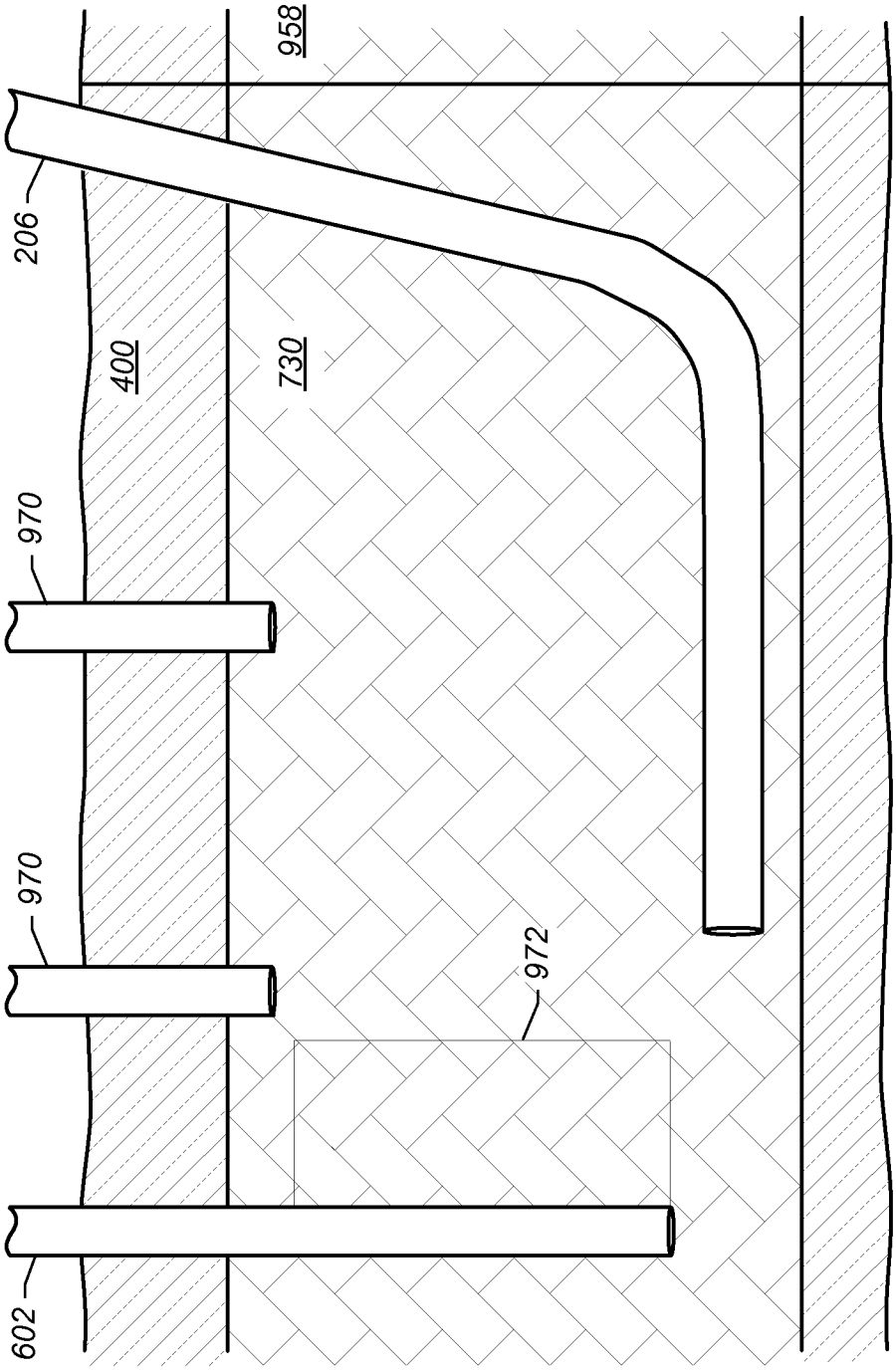


FIG. 241

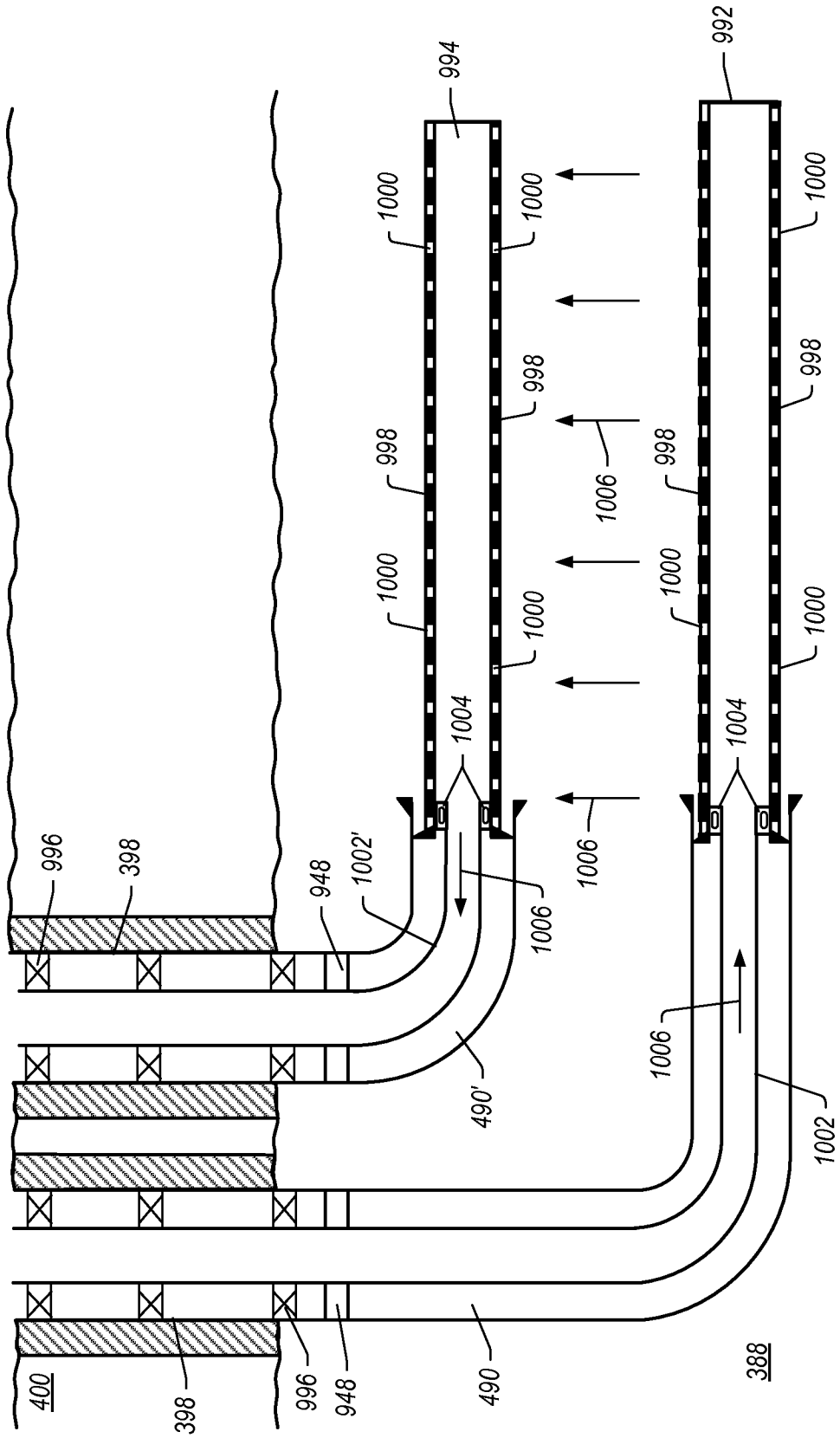

992
994
1000
998
1006
1004
1002'
1002
490'
490
996
398
948
400
388

FIG. 242

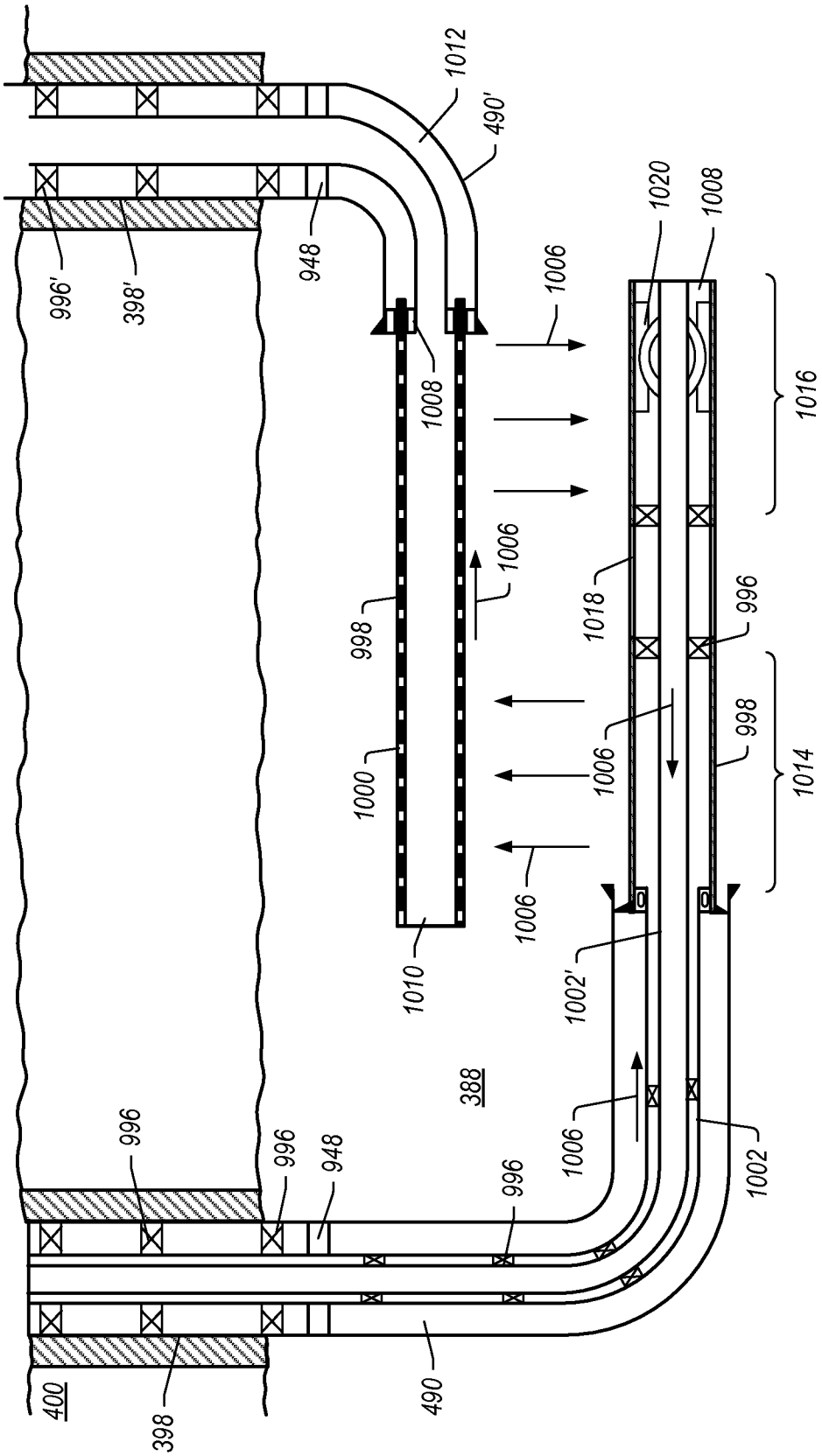

1012
490'
996'
398'
948
1020
1008
1006
1016
1018
996
998
1014
1000
1010
1002'
1002
388
400
398
490

FIG. 243

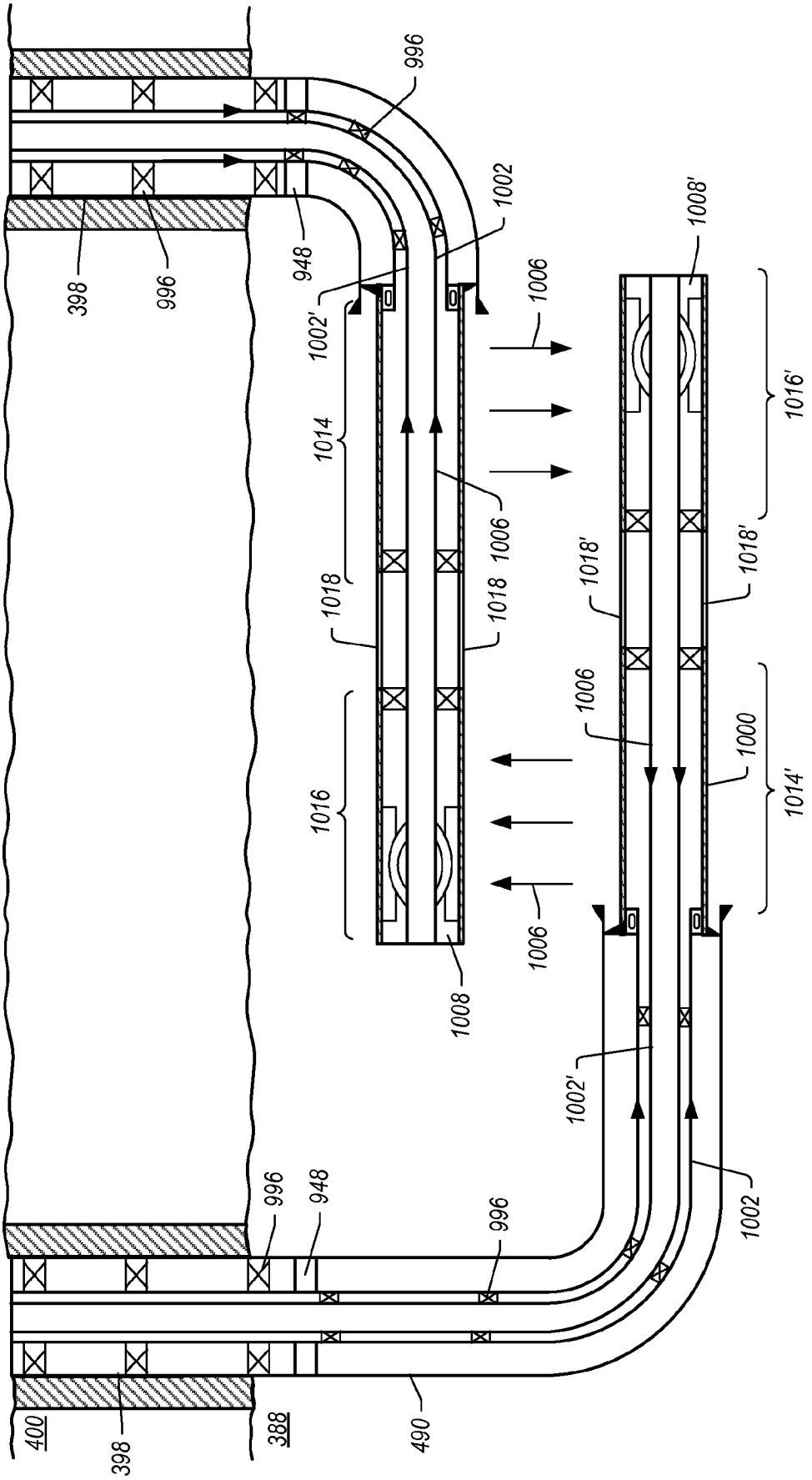

996
1002
948
398
996
1002'
1008'
1006
1014
1016'
1018'
1018
1018
1006
1018'
1006
1000
1016
1014'
1006
1008
1002'
996
948
996
1002
400
398
388
490

FIG. 244

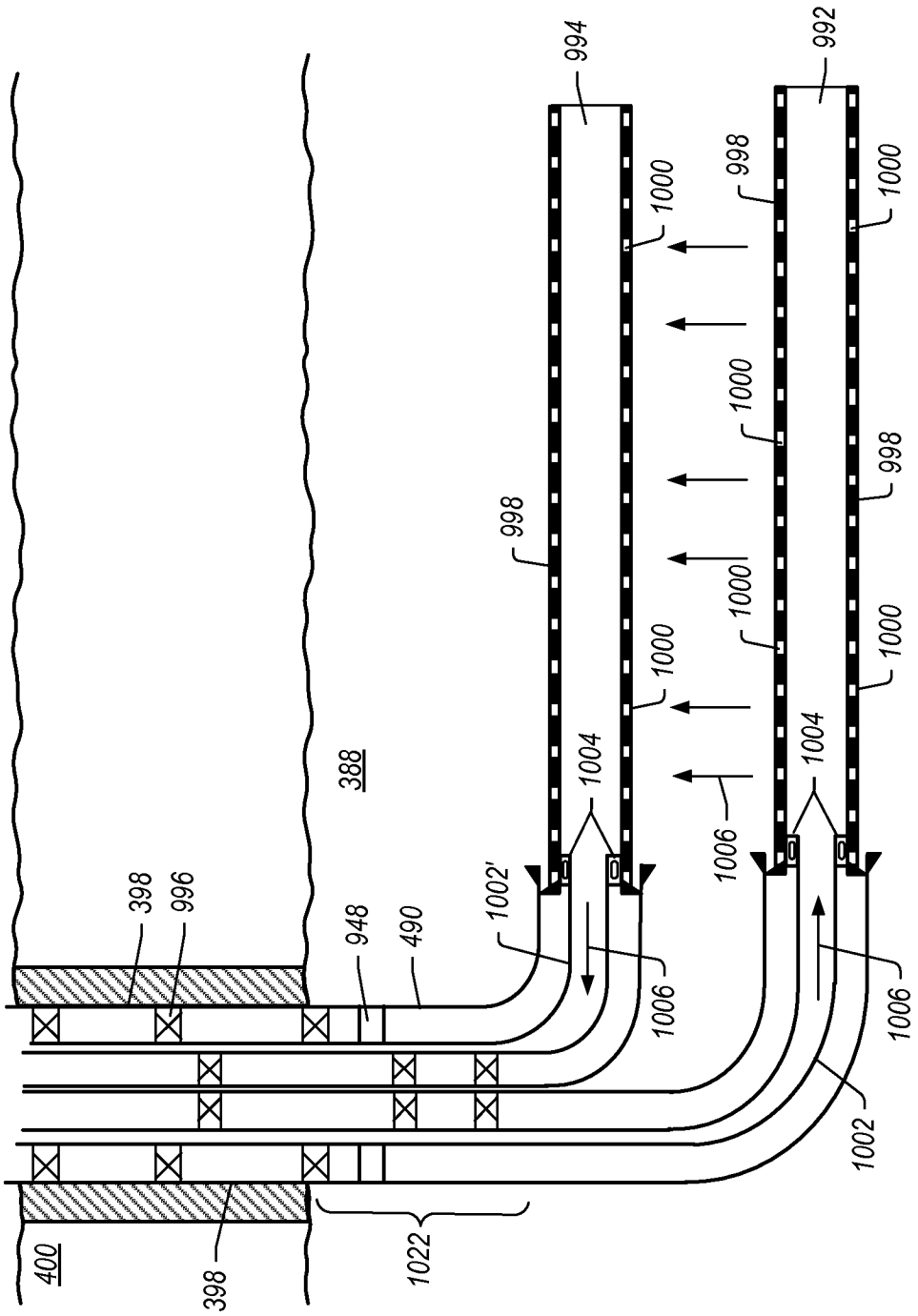

994
992
998
1000
1004
1006
1002'
1002
948
490
398
996
388
400
1022

FIG. 245

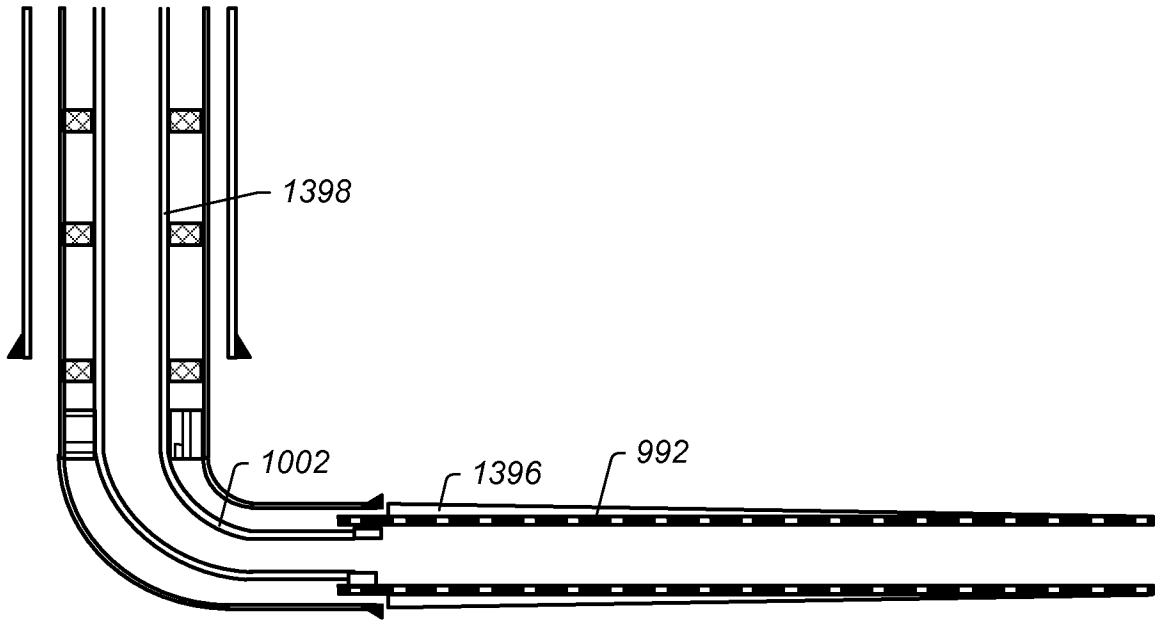


FIG. 246

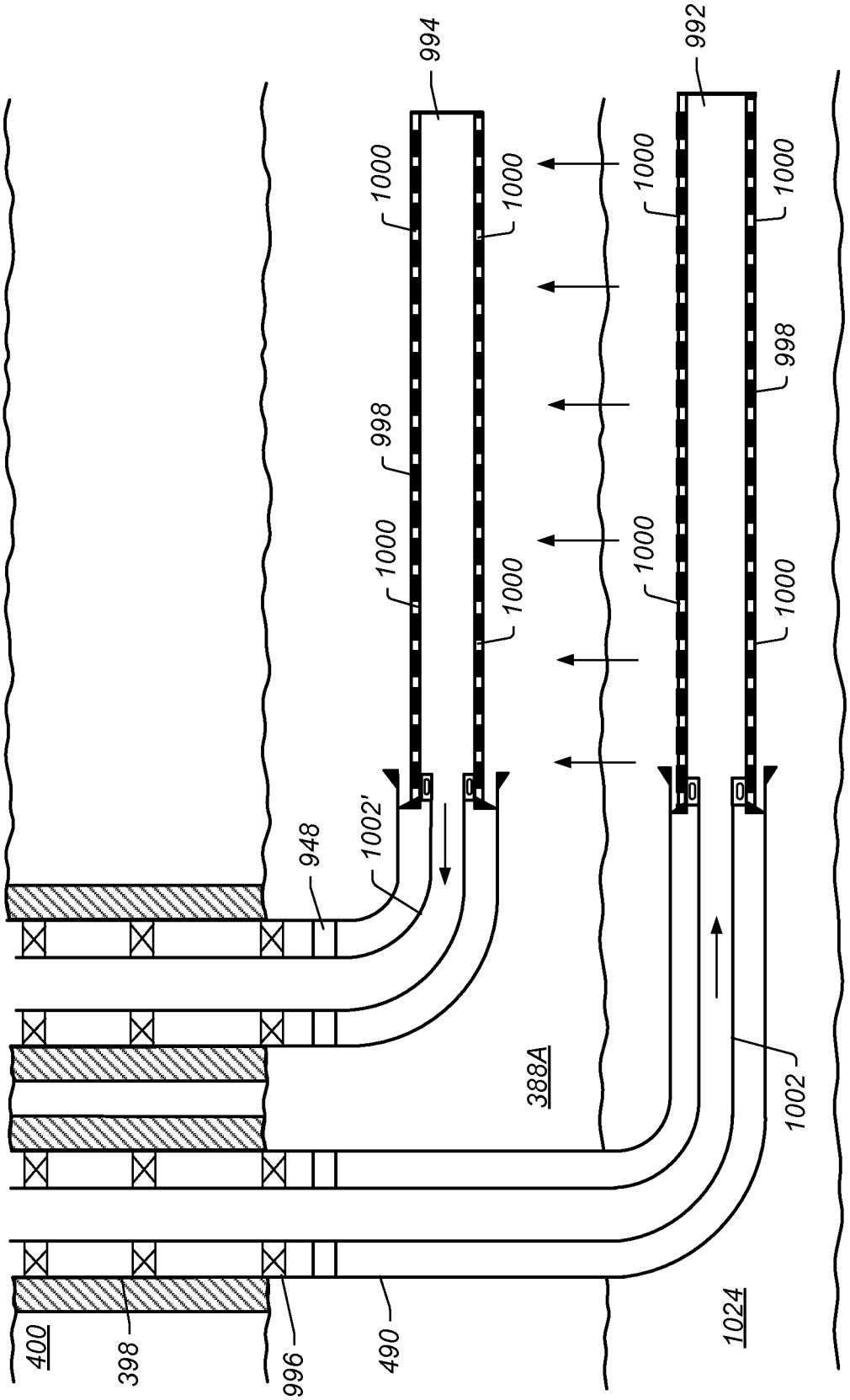


FIG. 247

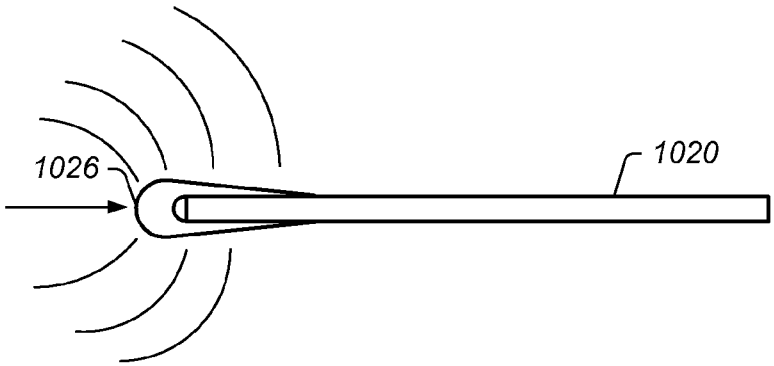


FIG. 248A

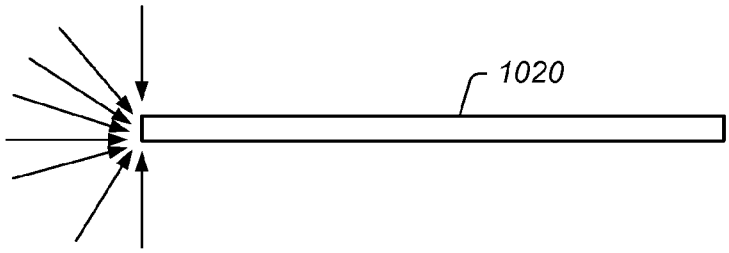


FIG. 248B

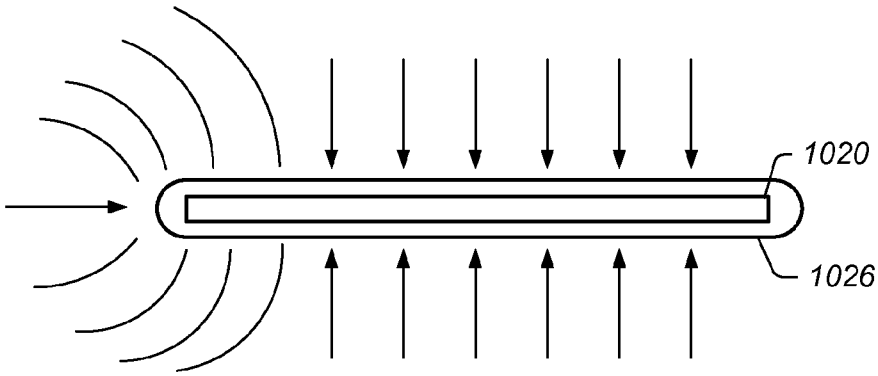


FIG. 249A



FIG. 249B

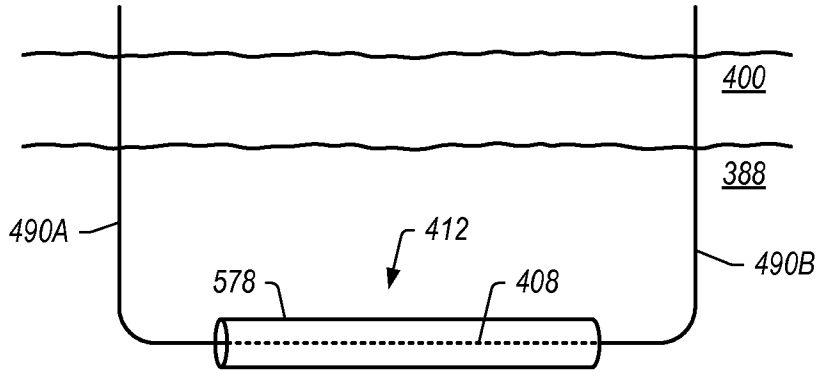


FIG. 250

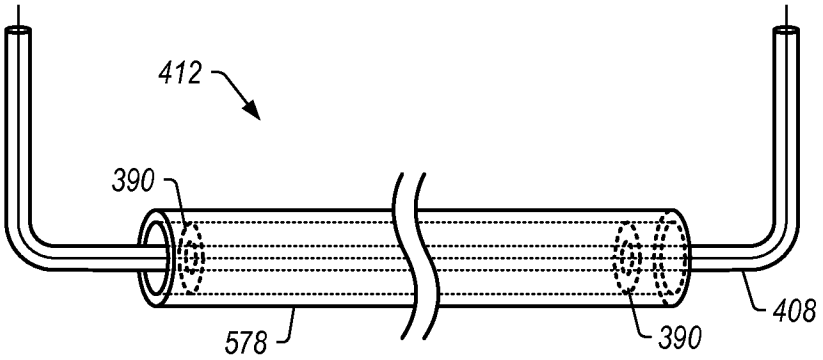


FIG. 251

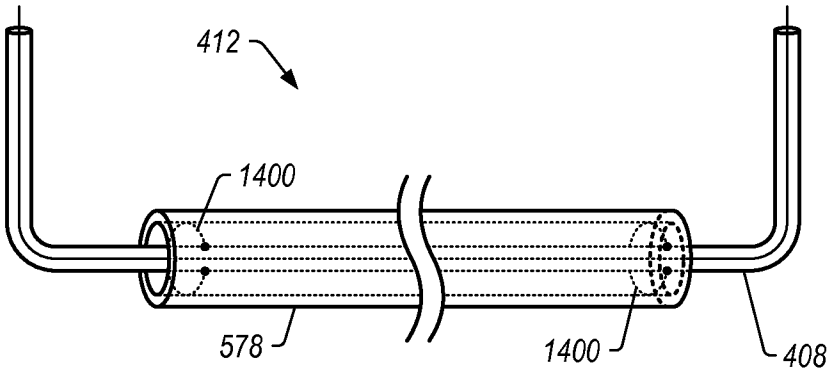


FIG. 252

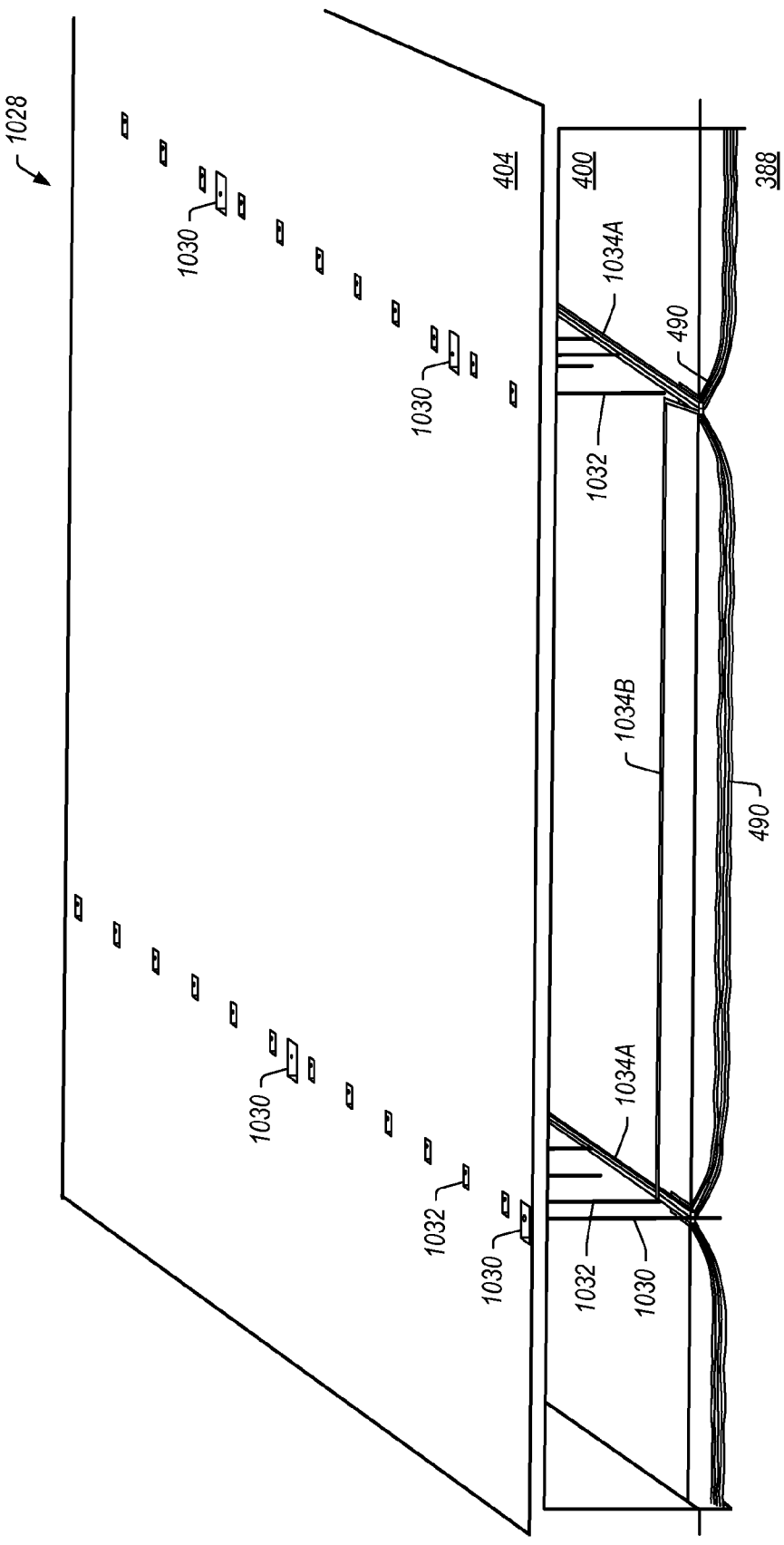

1028
1030
404
400
388
1034A
490
1032
1034B
490
1034A
1032
1030
1032
1030
1030

FIG. 253

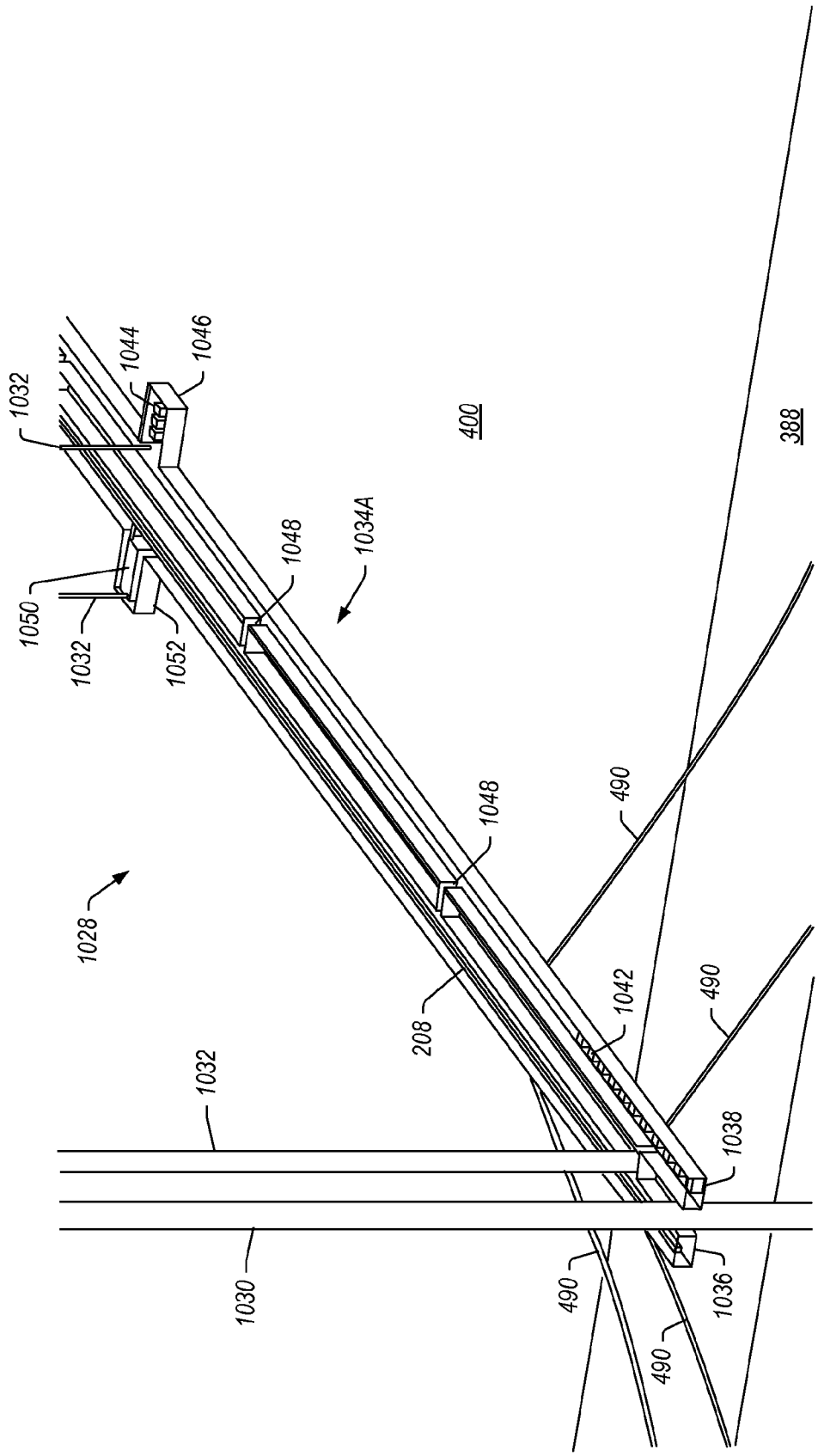

1032
1044
1046
400
388
1034A
1048
1050
1032
1052
1028
1048
490
208
1042
490
1032
1038
1030
490
1036
490

FIG. 254

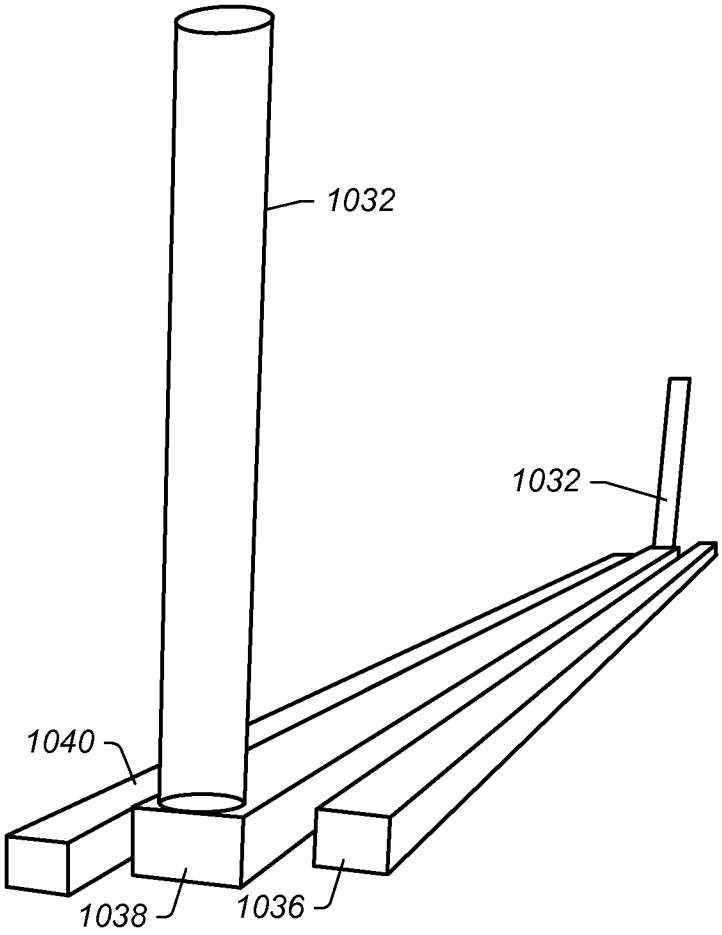


FIG. 255

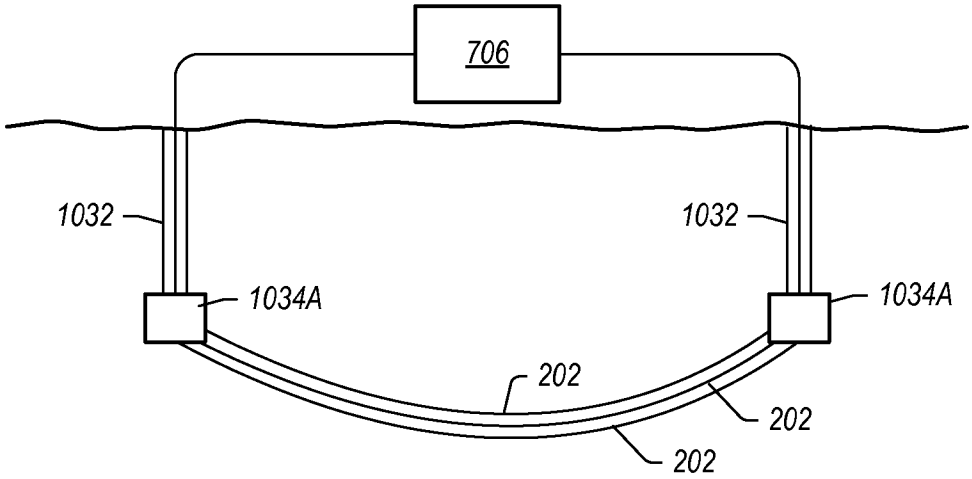


FIG. 256

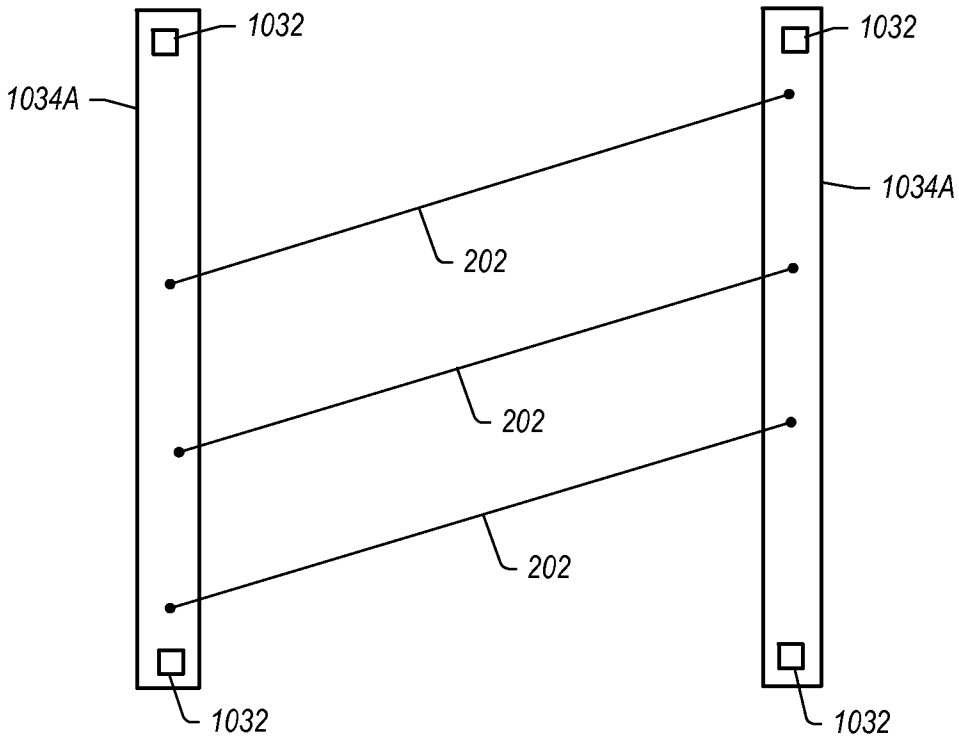


FIG. 257

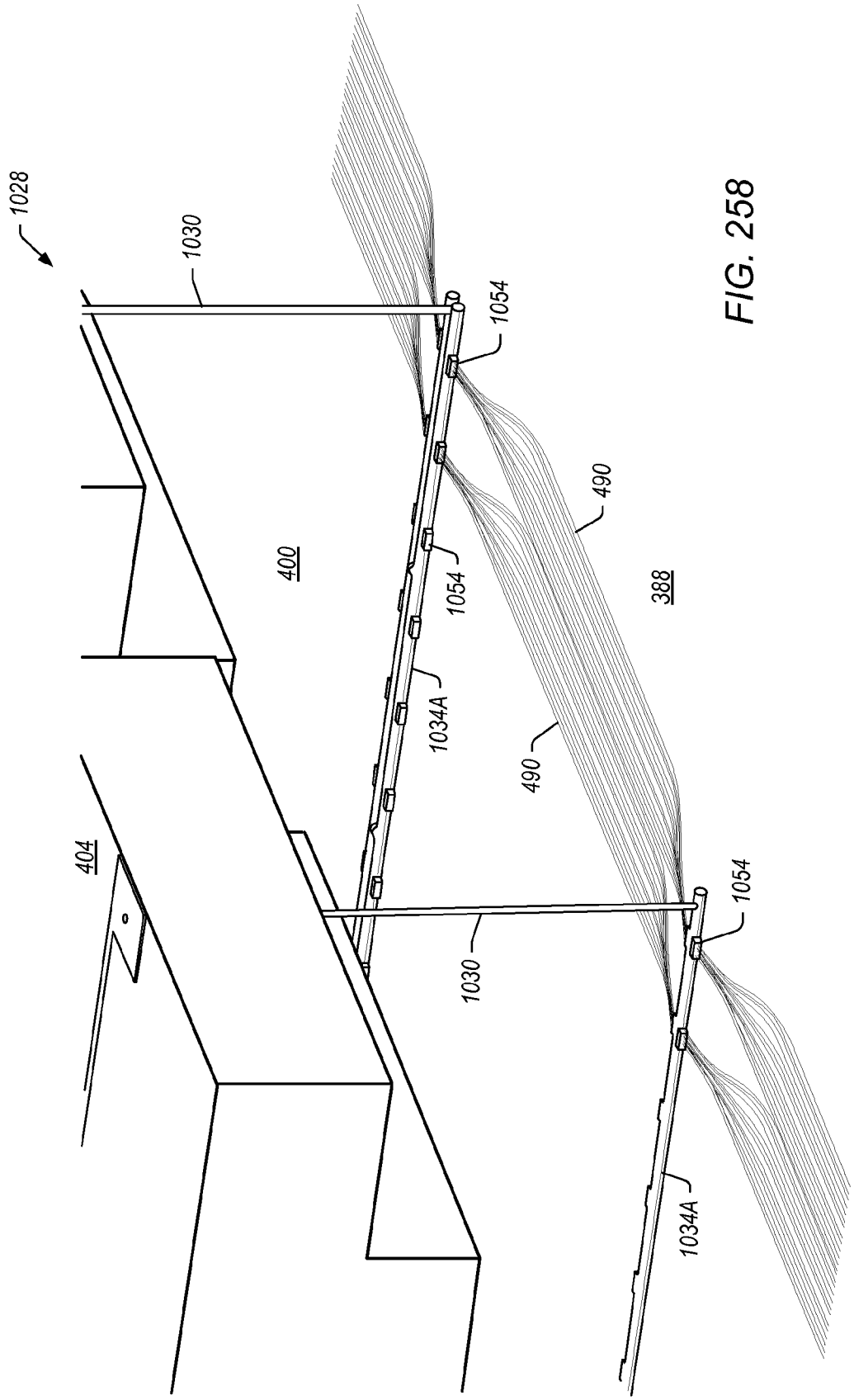


FIG. 258

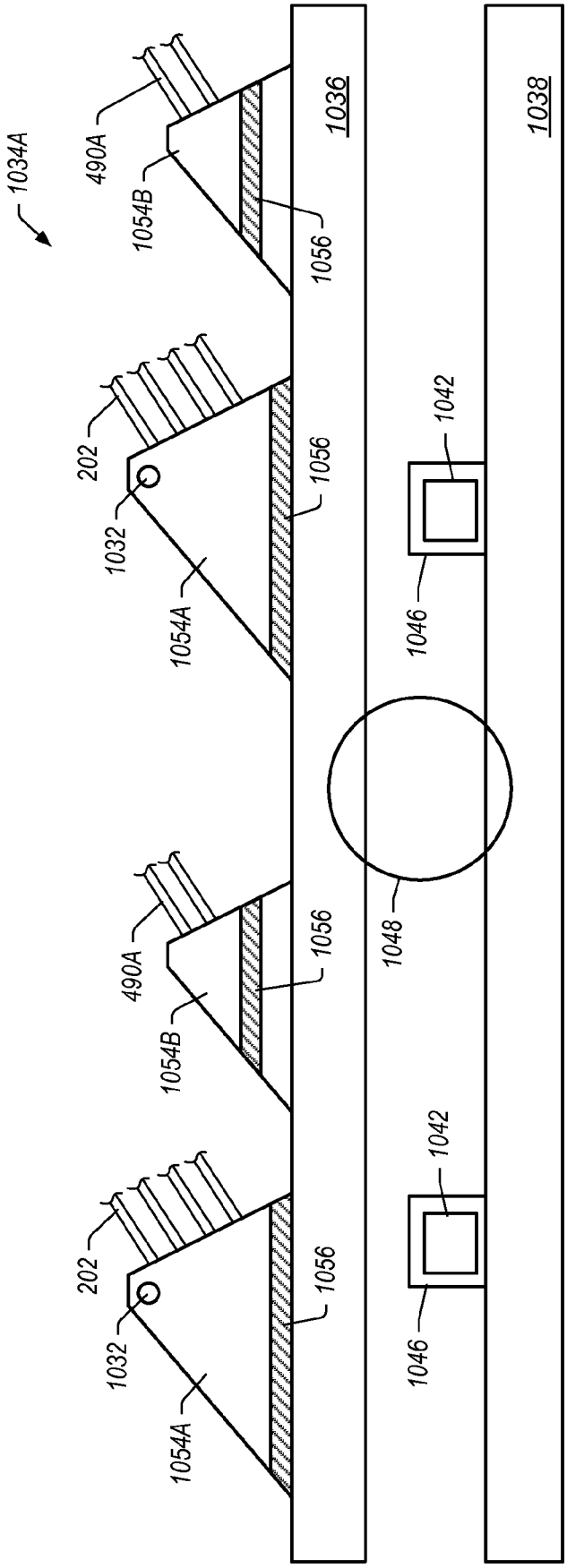

1034A
490A
1054B
1036
1056
1038
202
1032
1054A
1042
1046
1048

FIG. 259

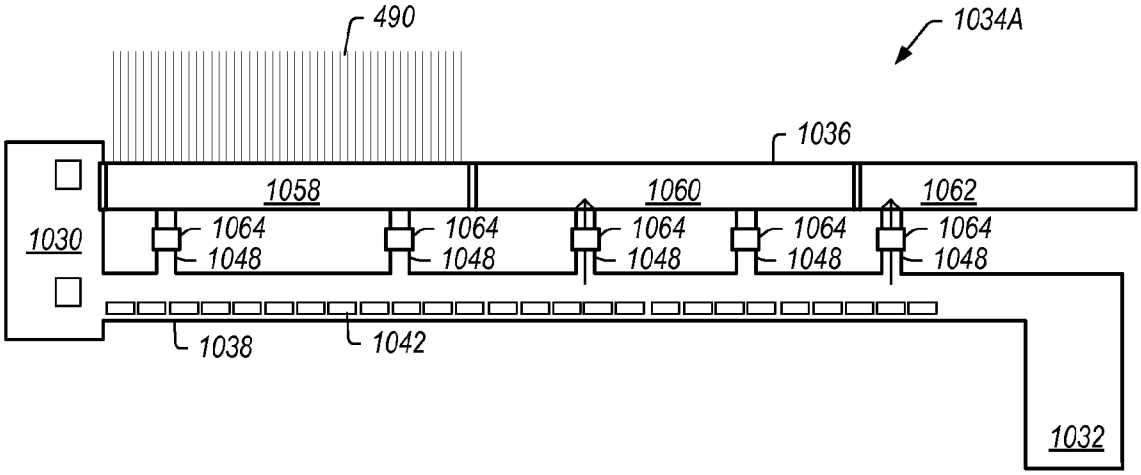


FIG. 260

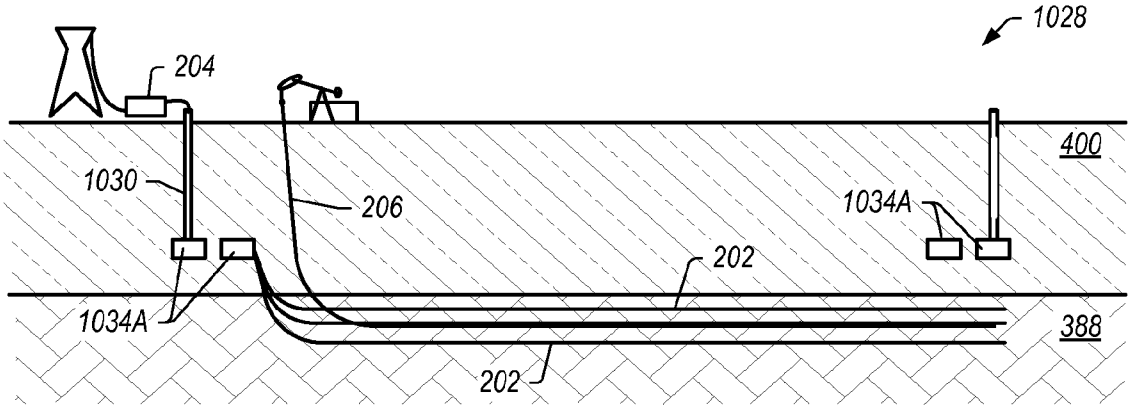


FIG. 261

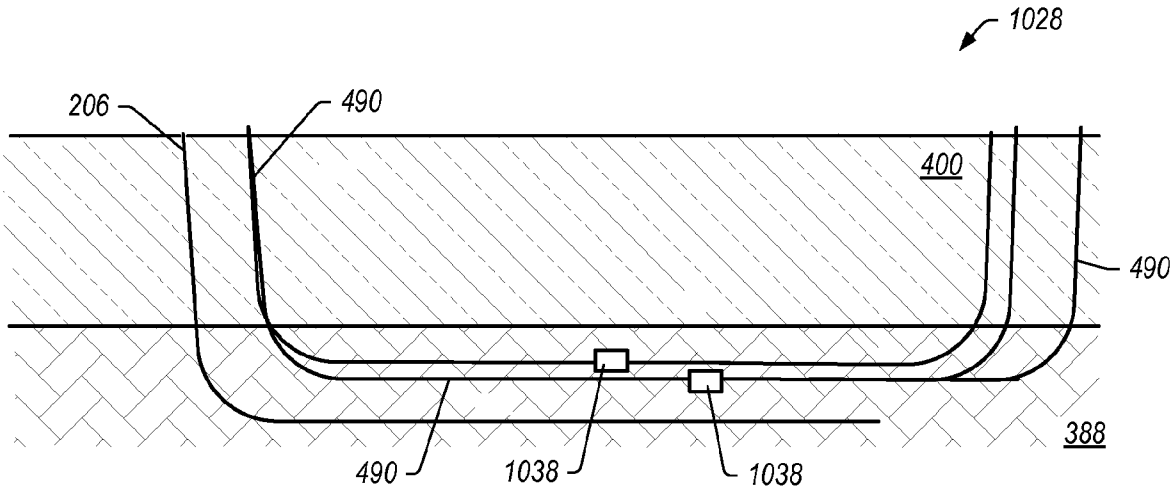


FIG. 262

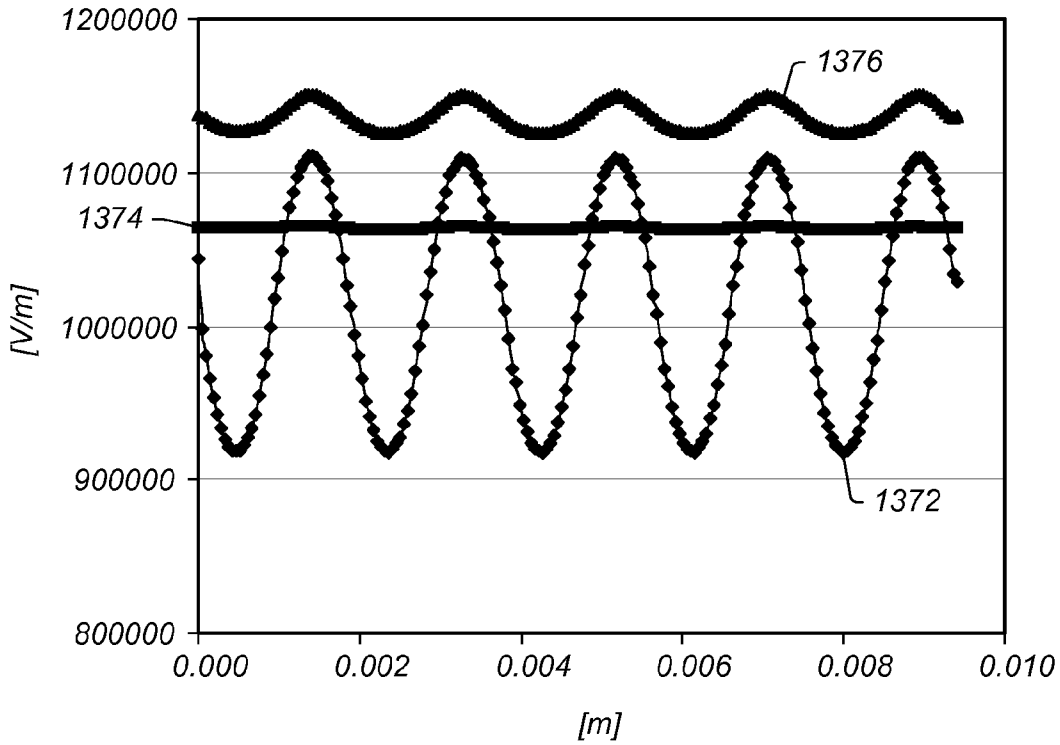


FIG. 263

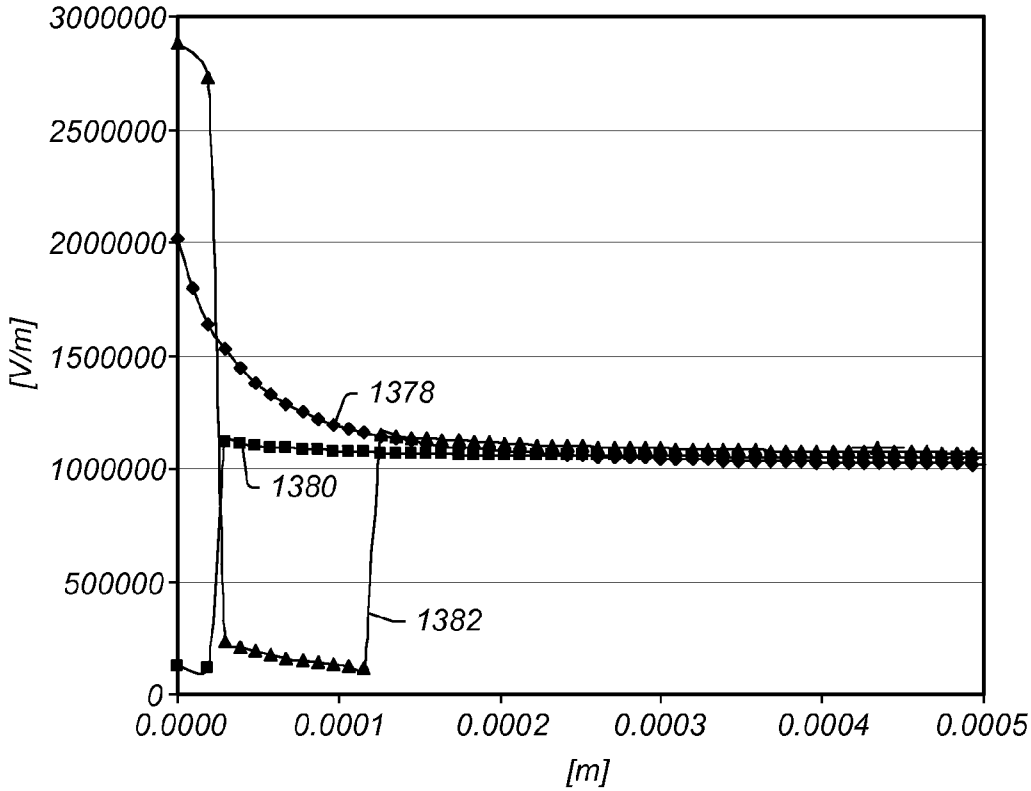


FIG. 264

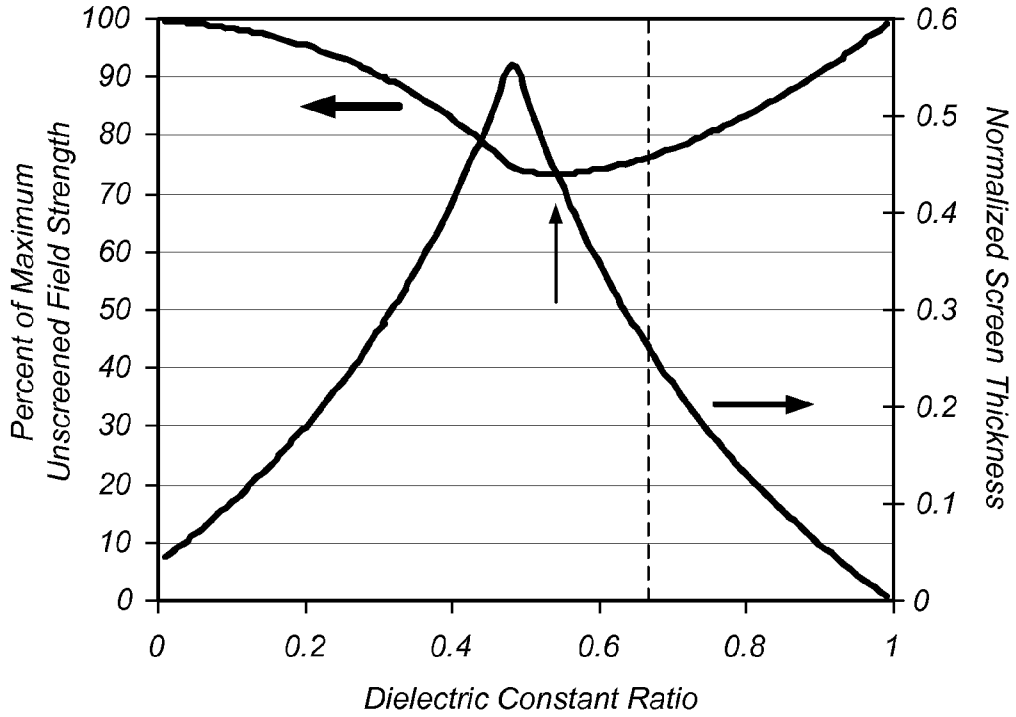


FIG. 265

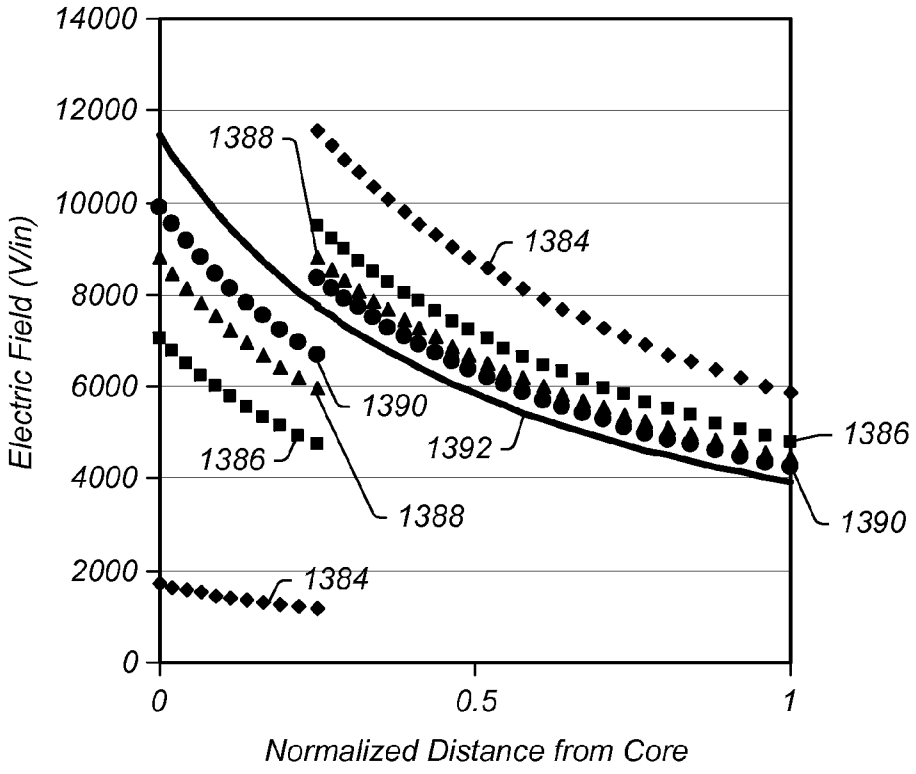


FIG. 266

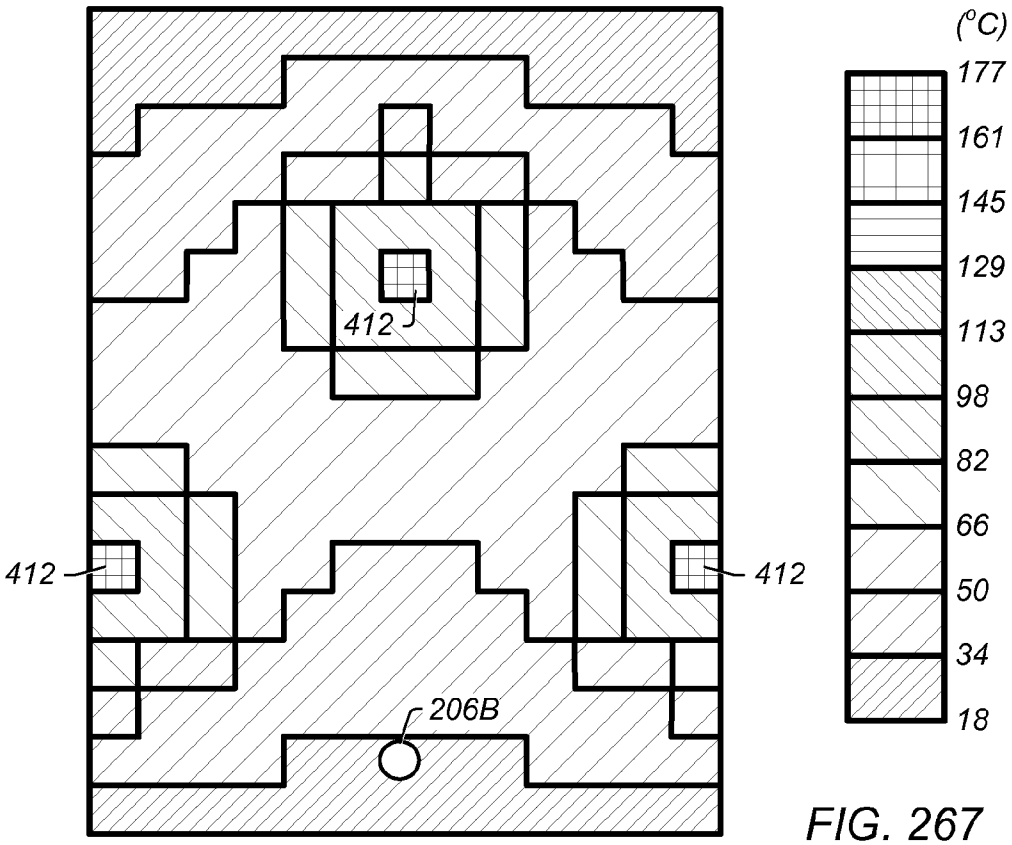


FIG. 267

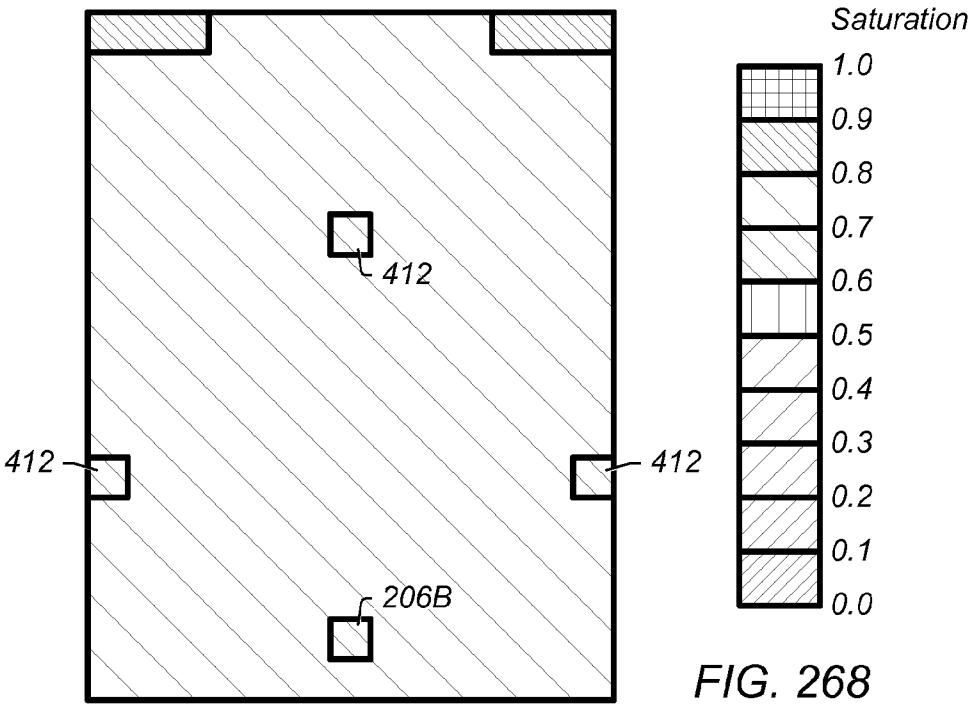


FIG. 268

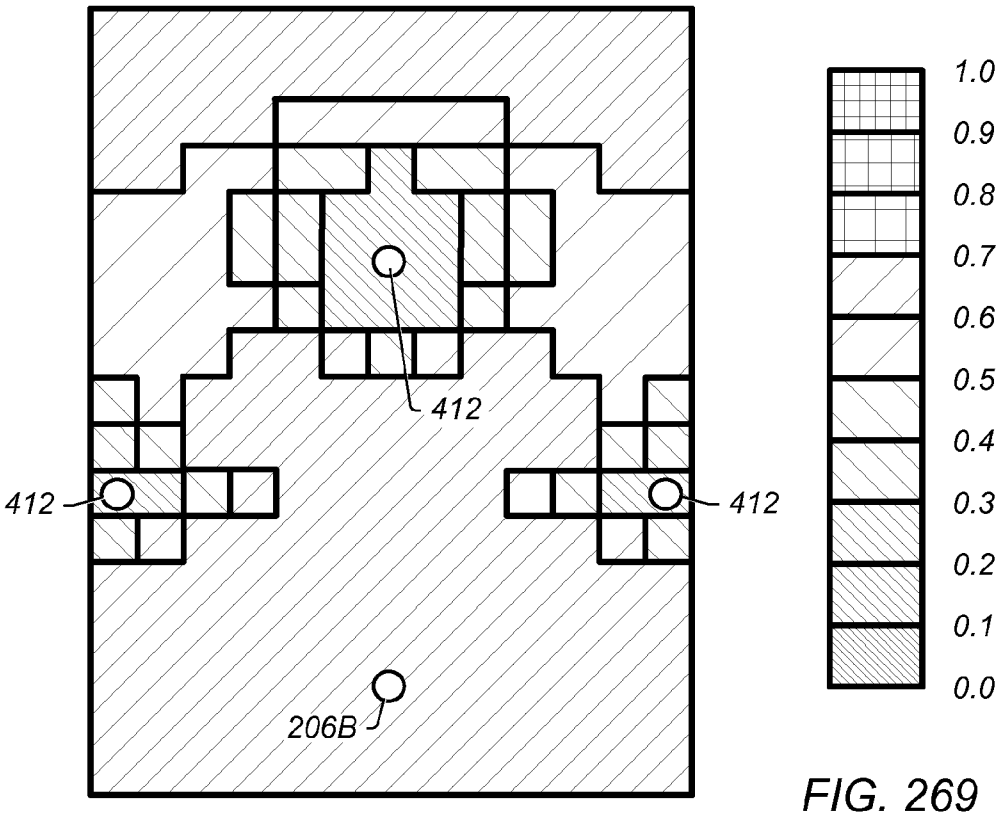


FIG. 269

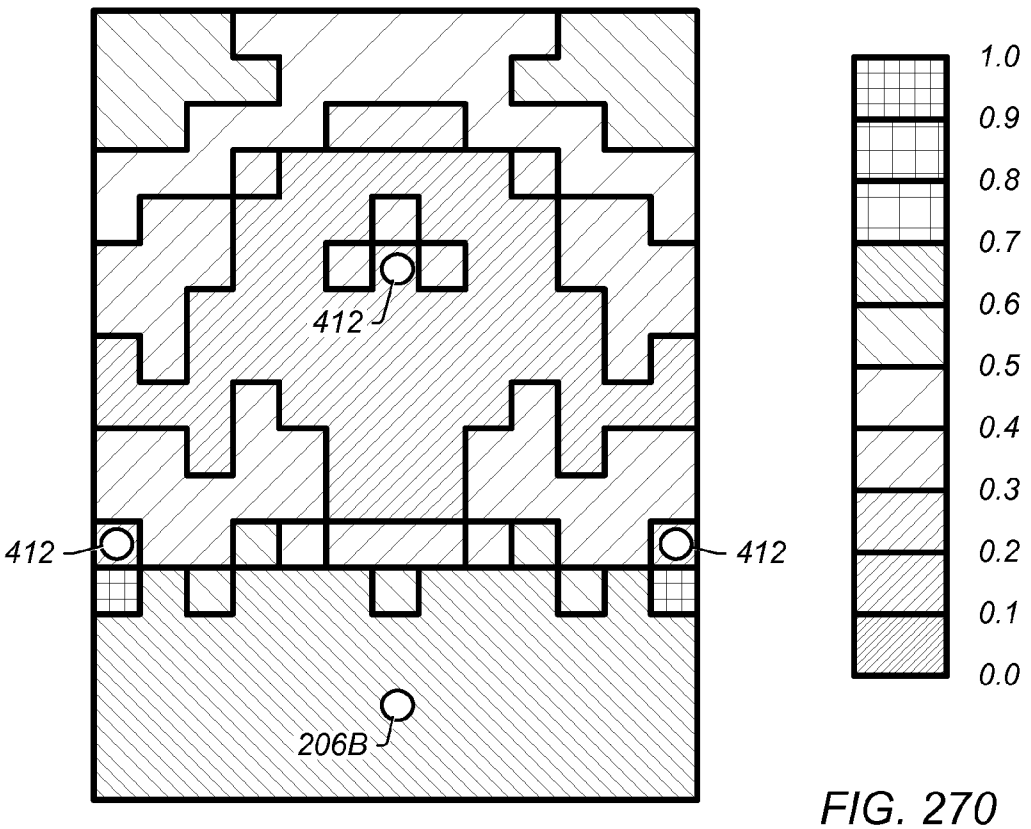


FIG. 270

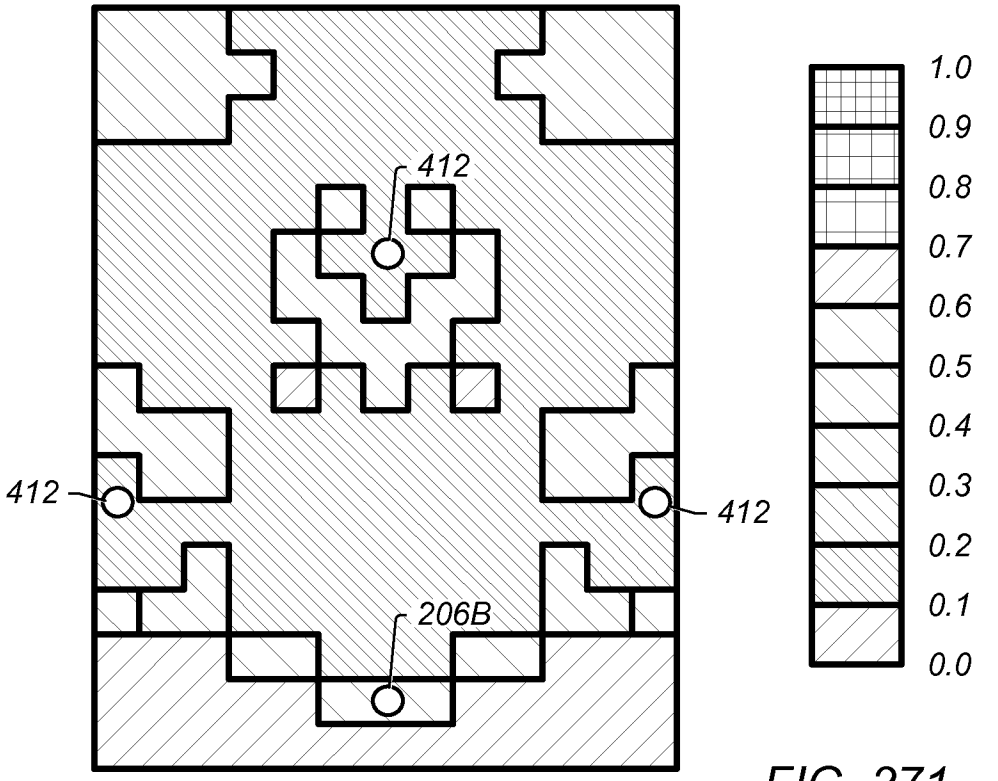


FIG. 271

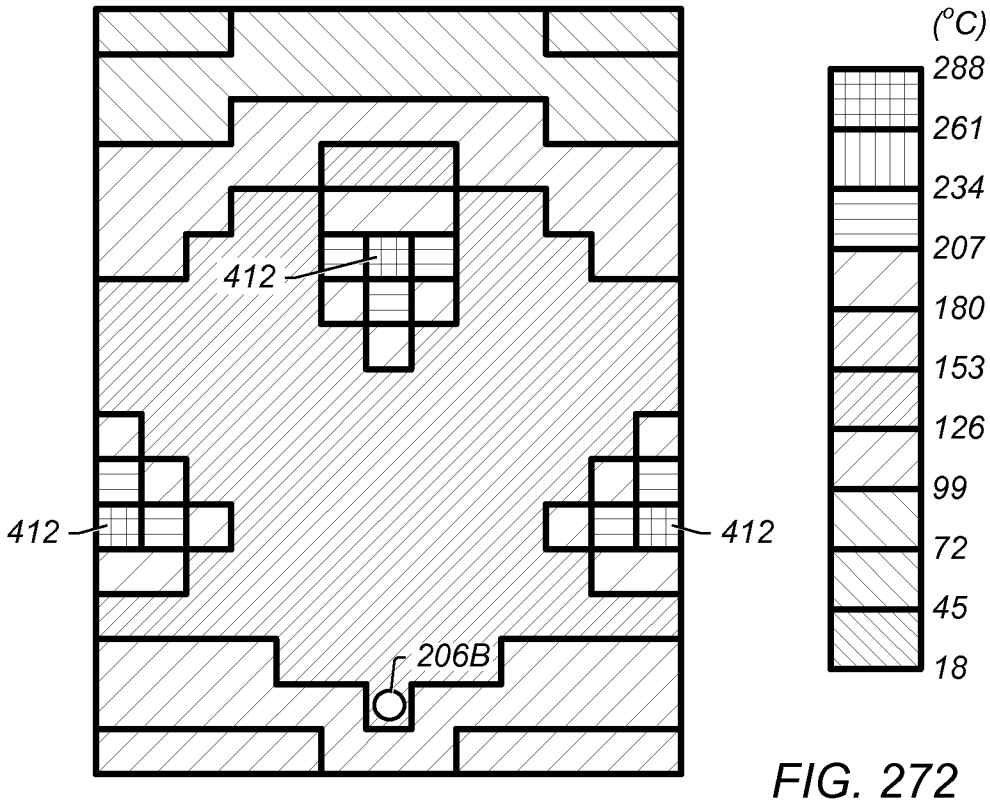


FIG. 272

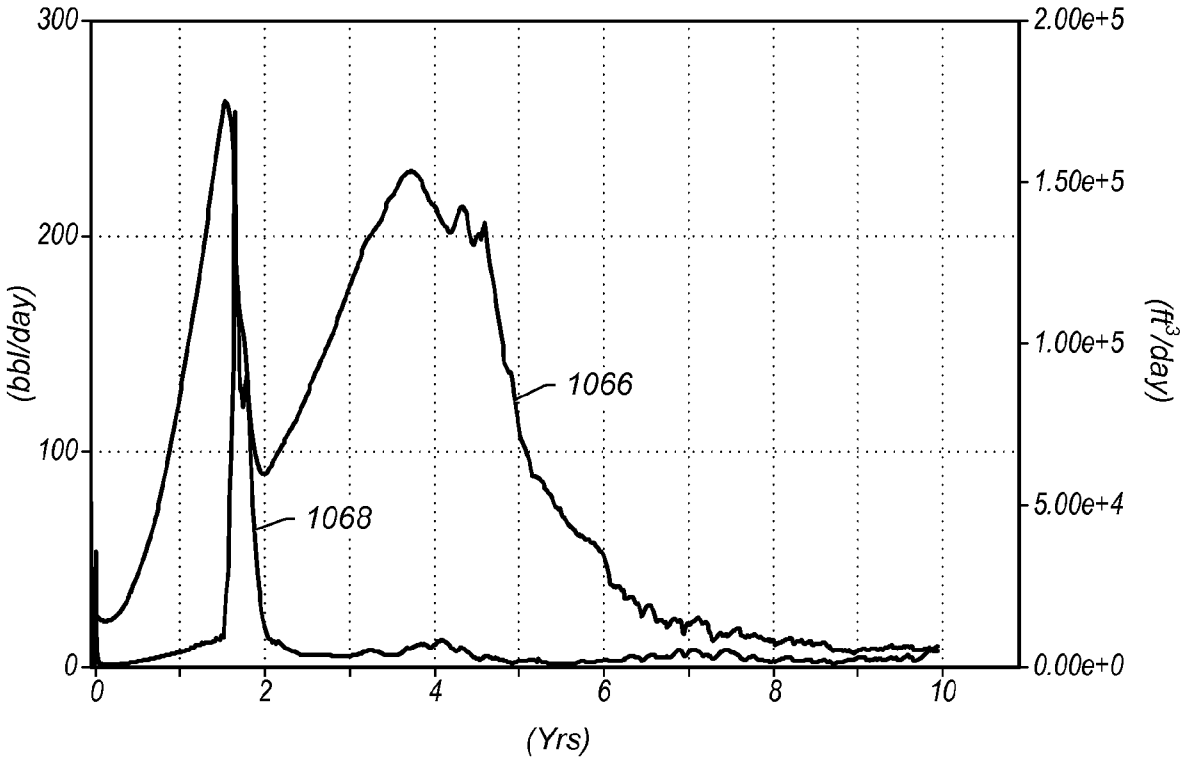


FIG. 273

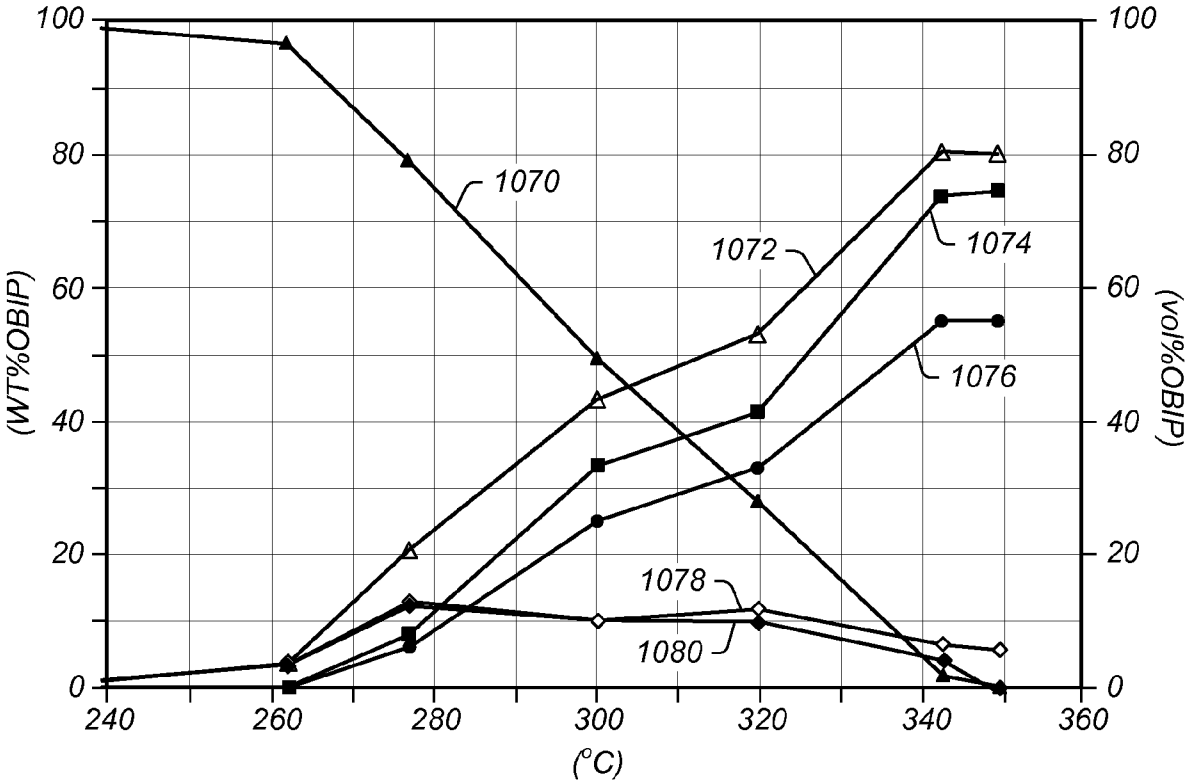


FIG. 274

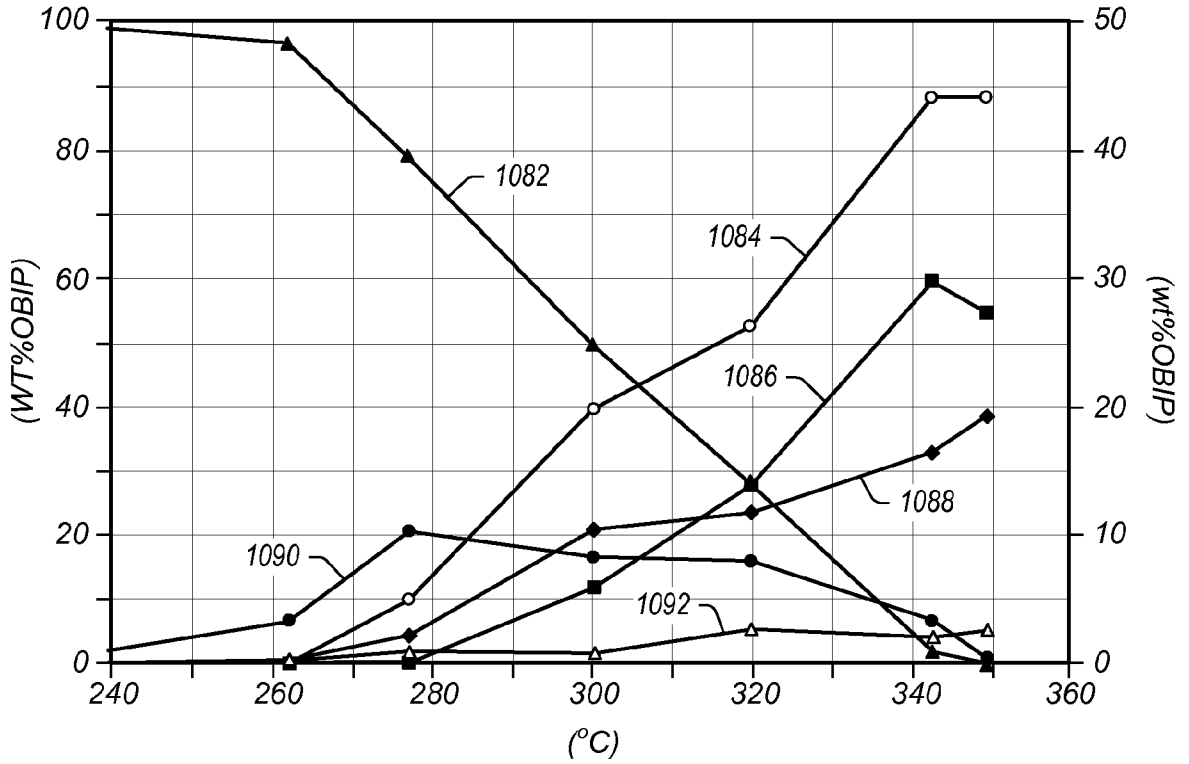


FIG. 275

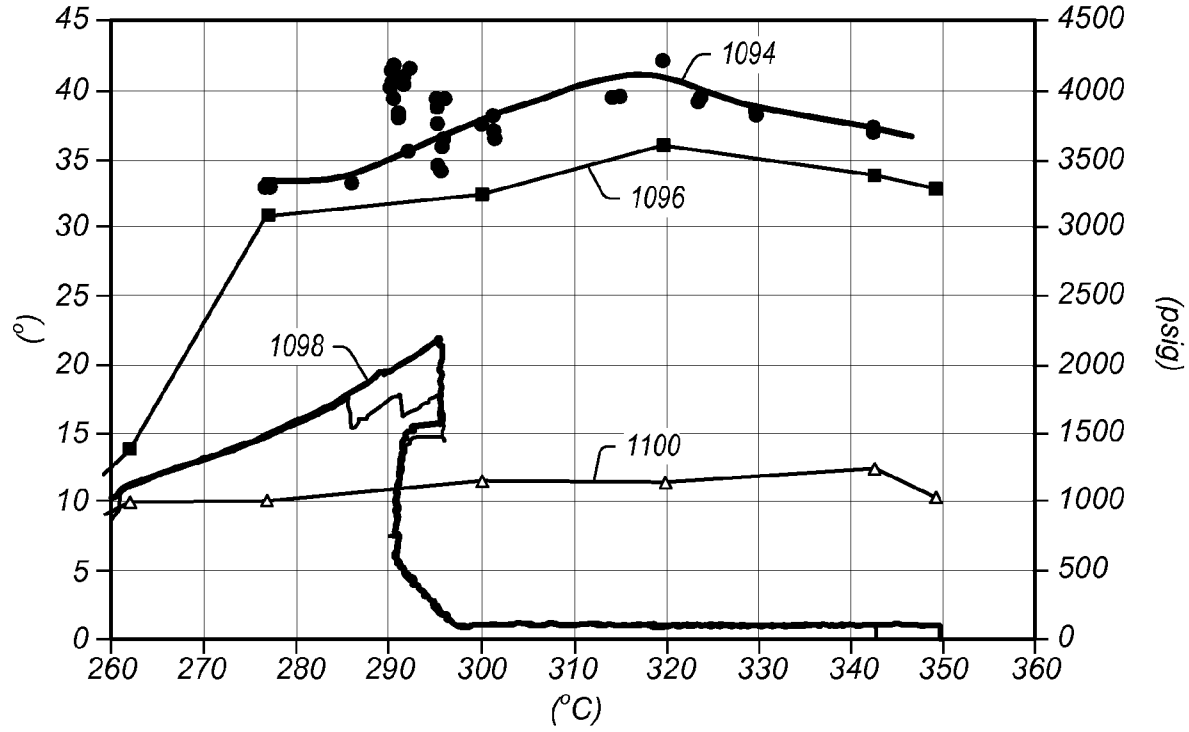
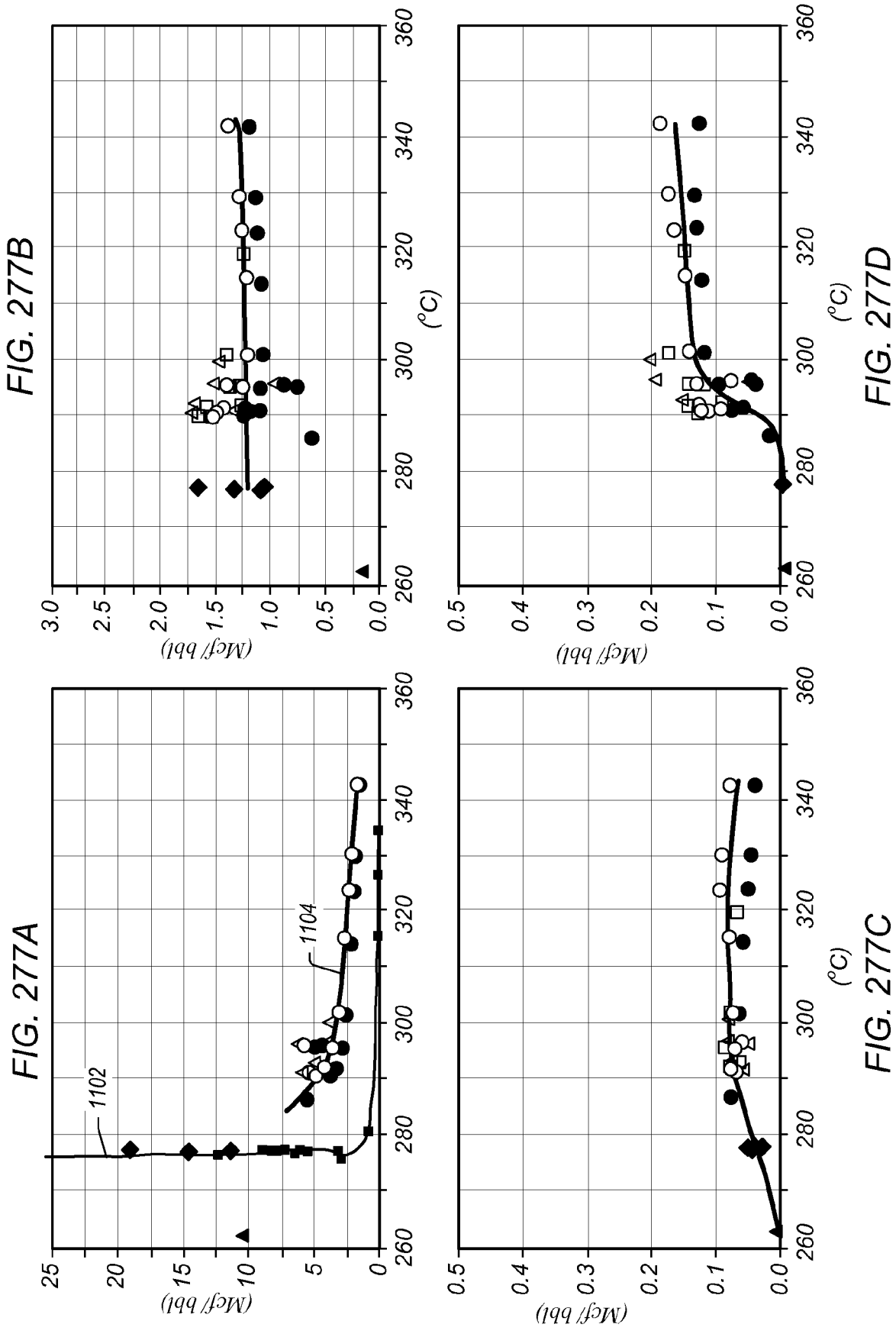


FIG. 276


FIG. 277A
FIG. 277B
FIG. 277C
FIG. 277D
1102
1104
(Mcf/ bbl)
(°C)
0
5
10
15
20
25
0.0
0.1
0.2
0.3
0.4
0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
260
280
300
320
340
360

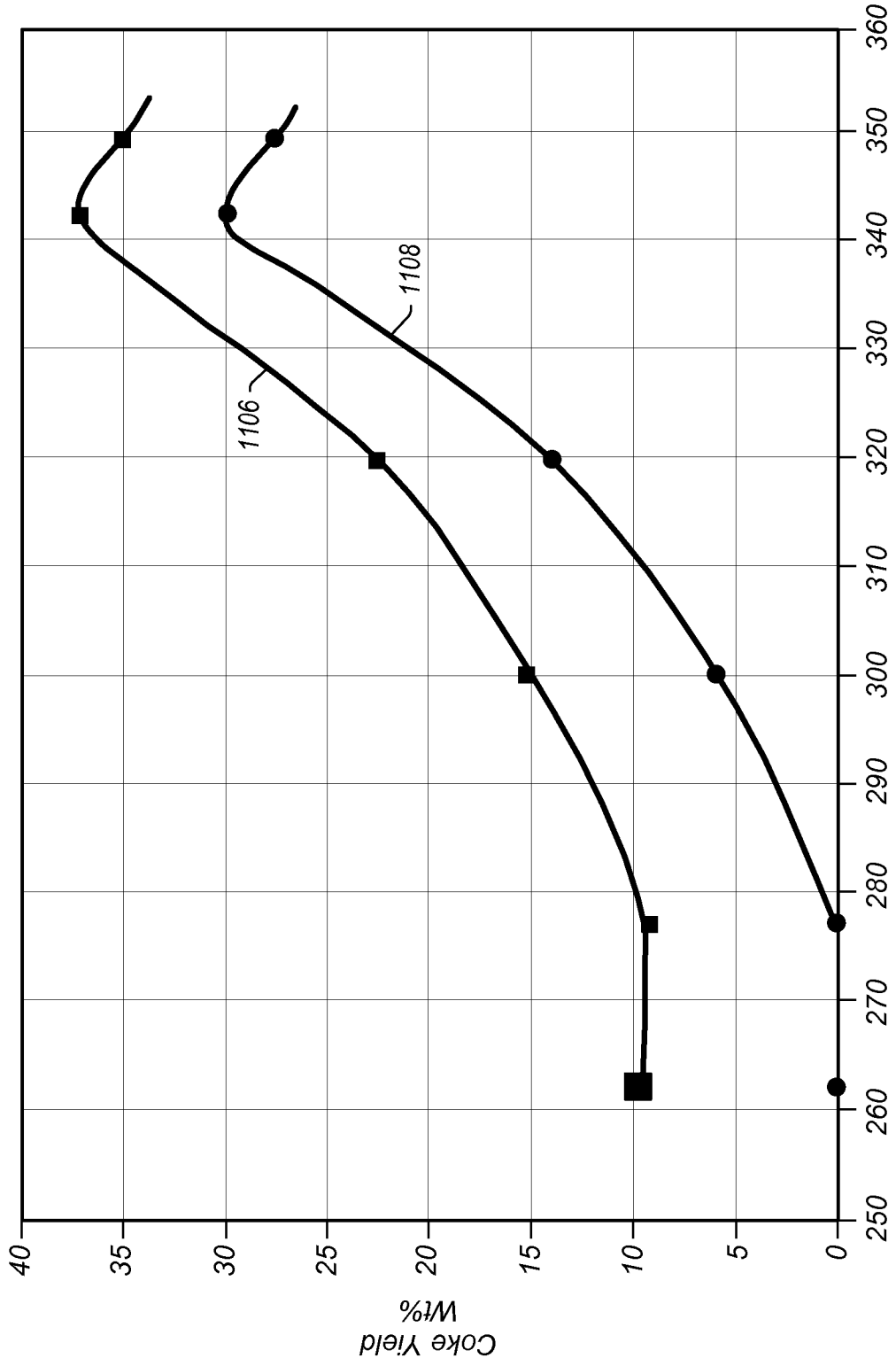

Coke Yield
Wt%
0
5
10
15
20
25
30
35
40
250
260
270
280
290
300
310
320
330
340
350
360
(°C)
1106
1108

FIG. 278

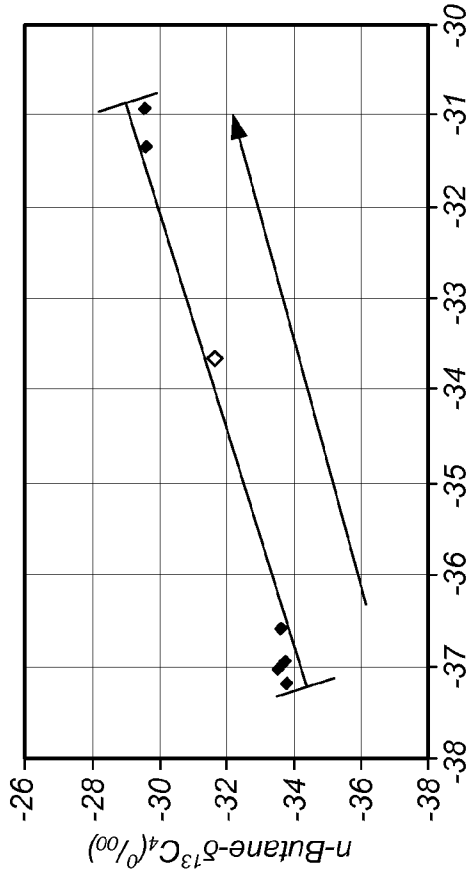


FIG. 279A

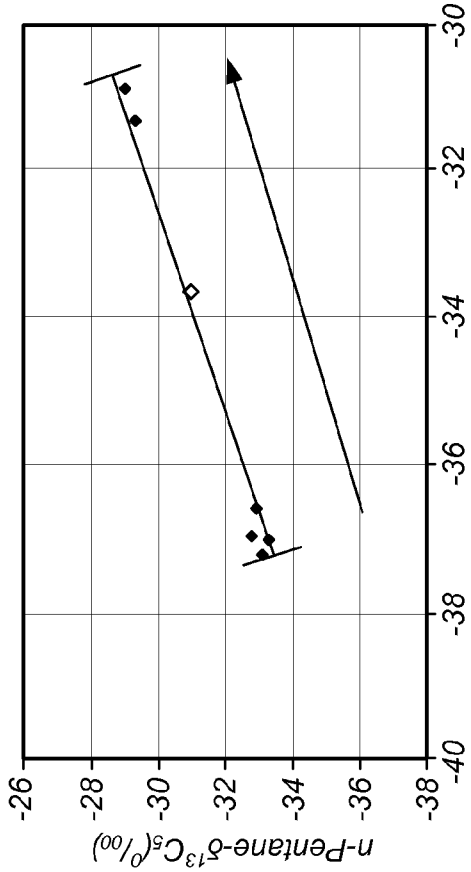


FIG. 279B

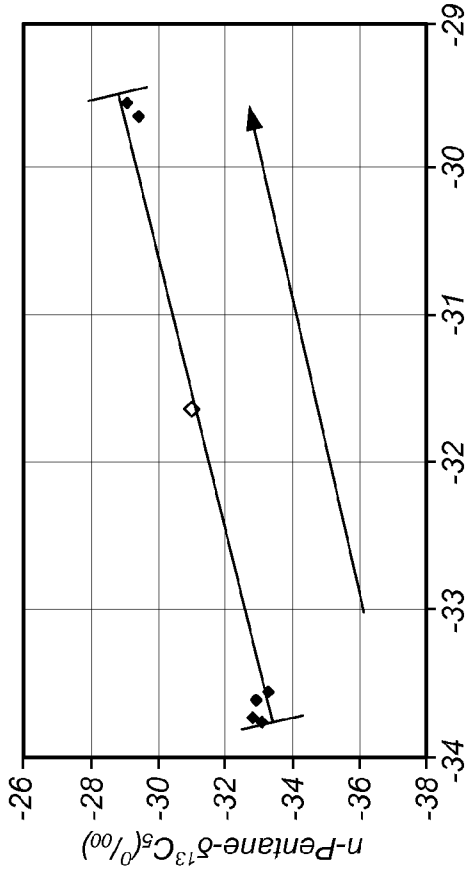


FIG. 279C

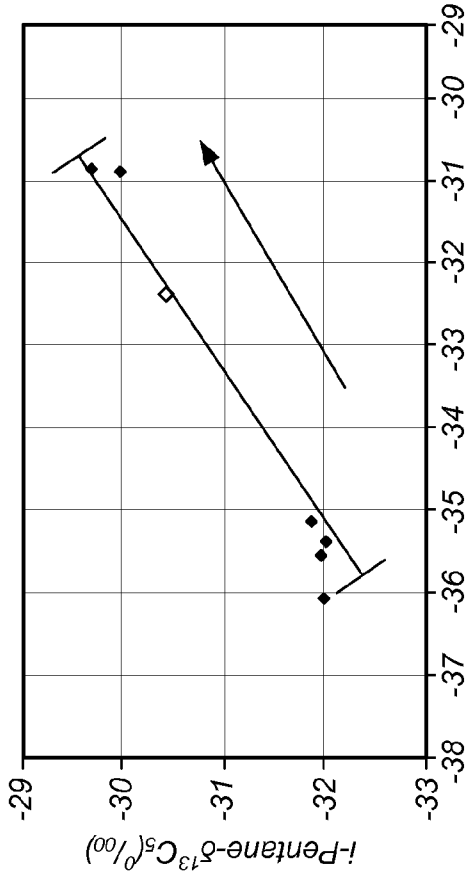


FIG. 279D

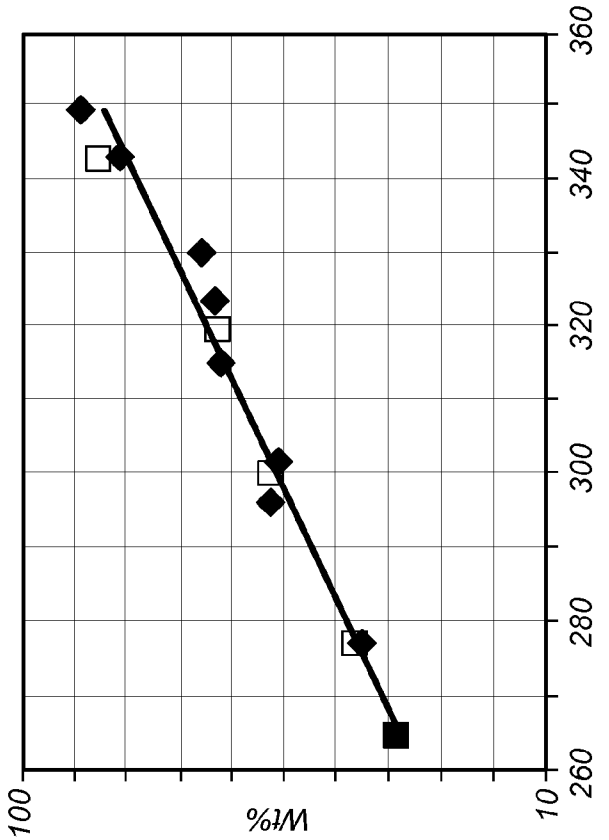


FIG. 281

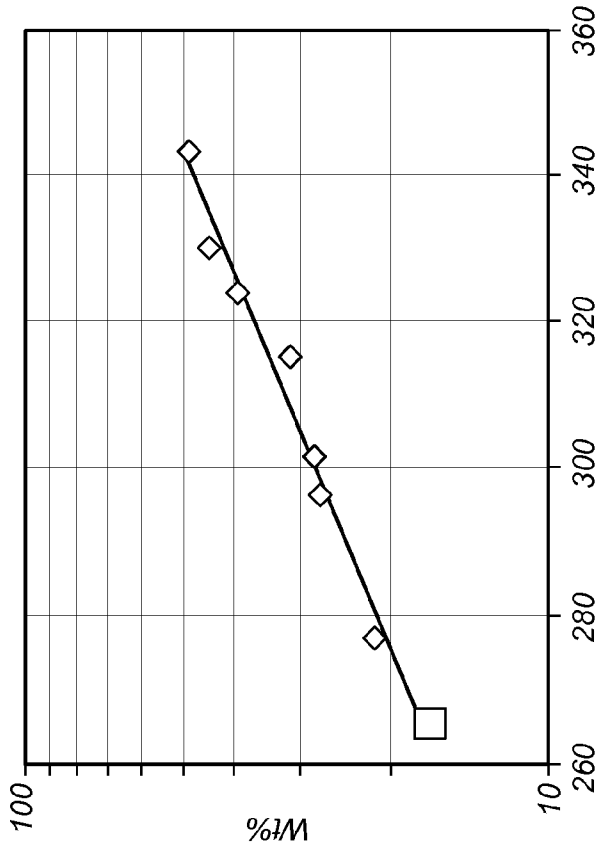


FIG. 280

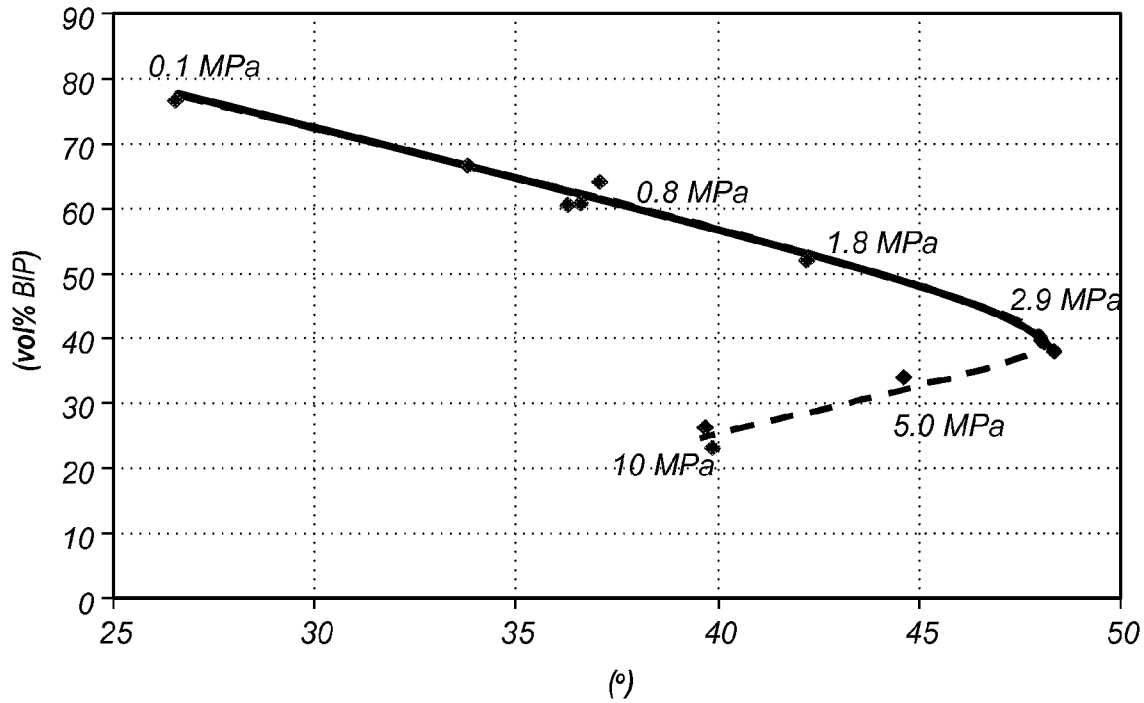


FIG. 282

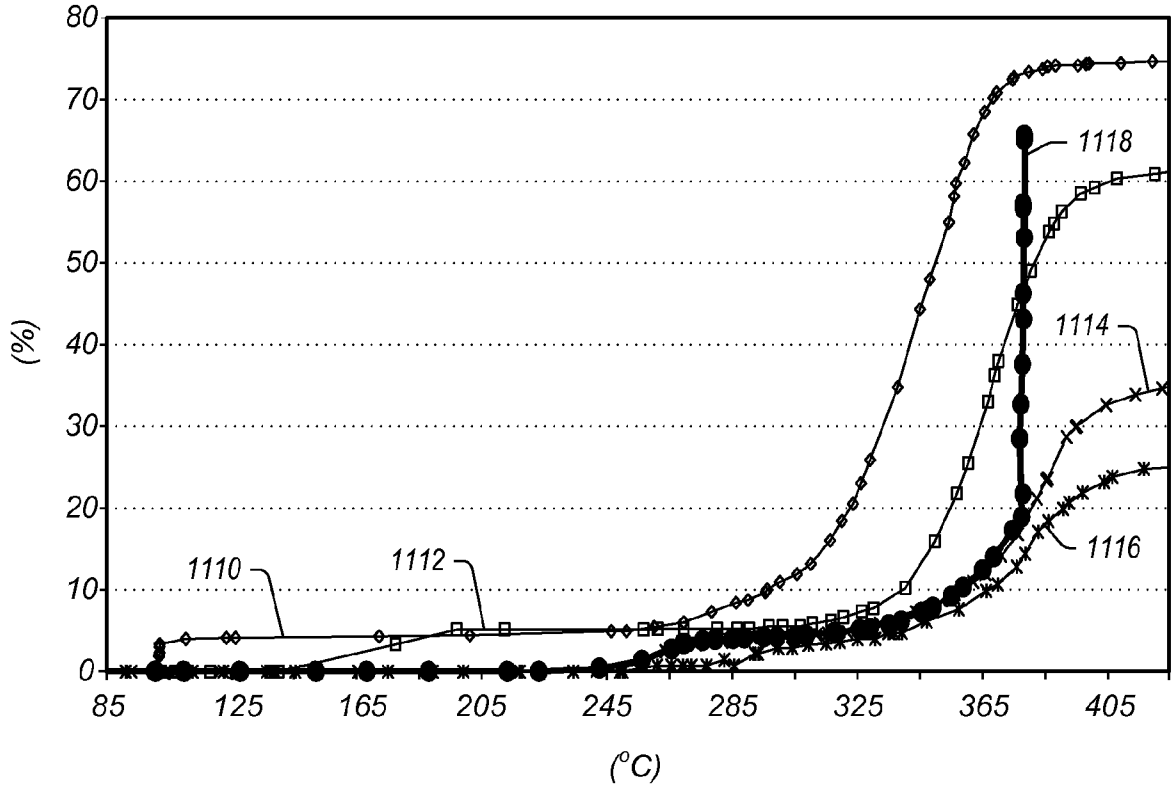


FIG. 283

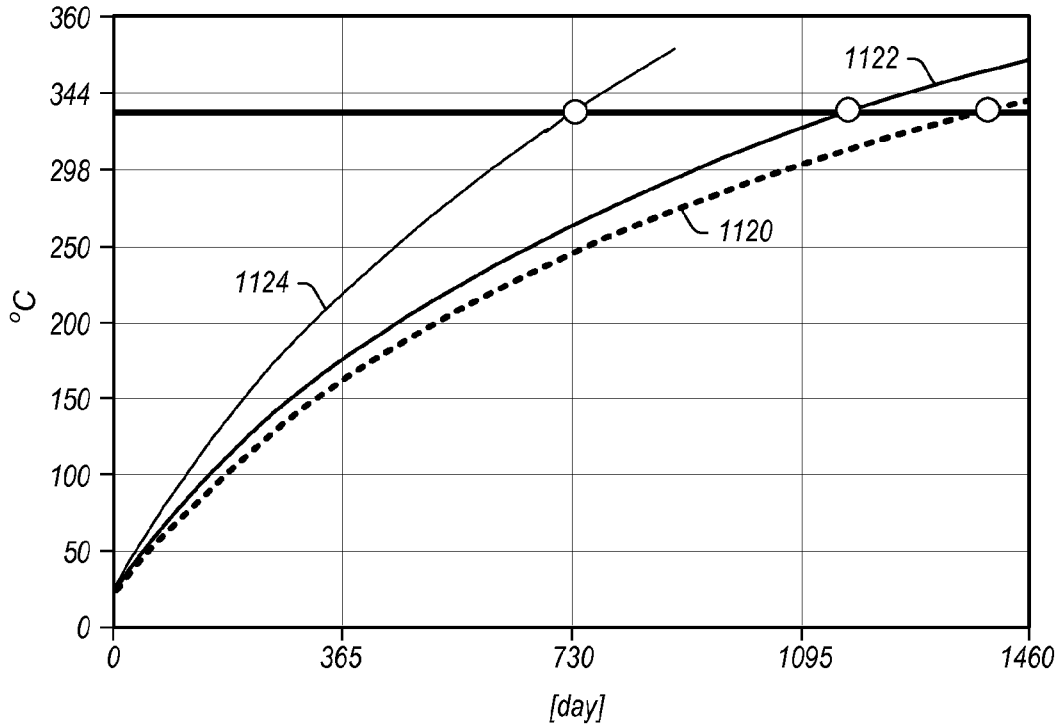


FIG. 284

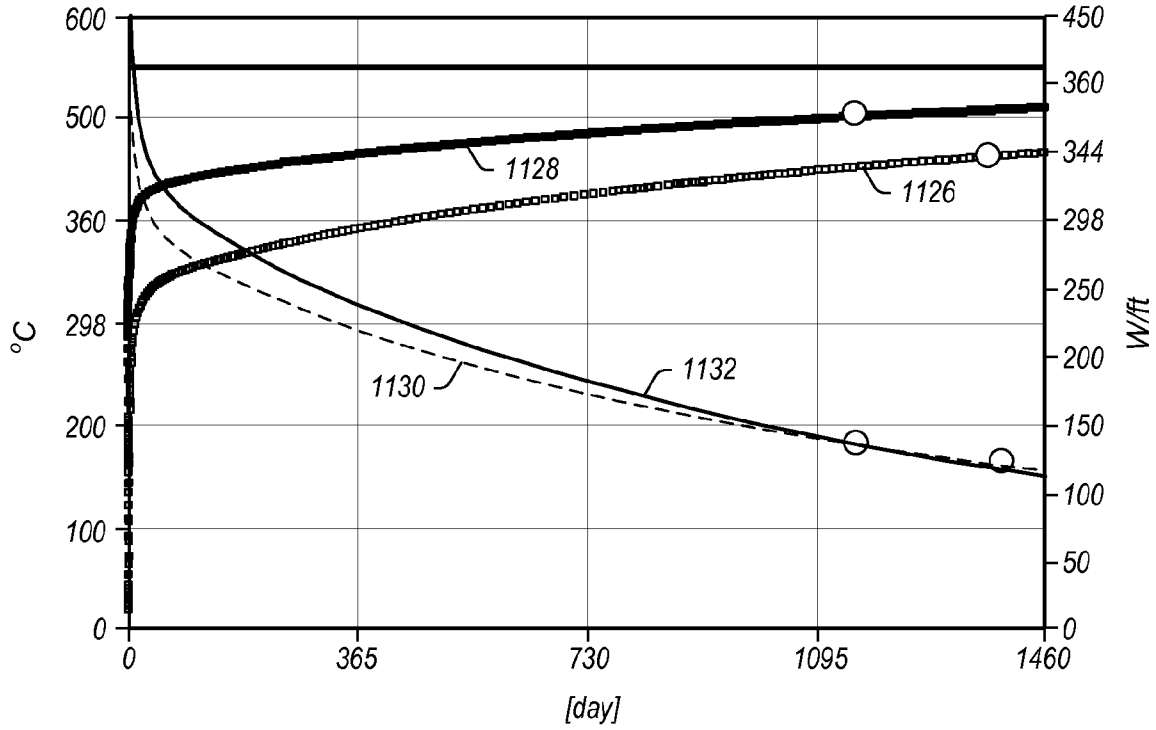


FIG. 285

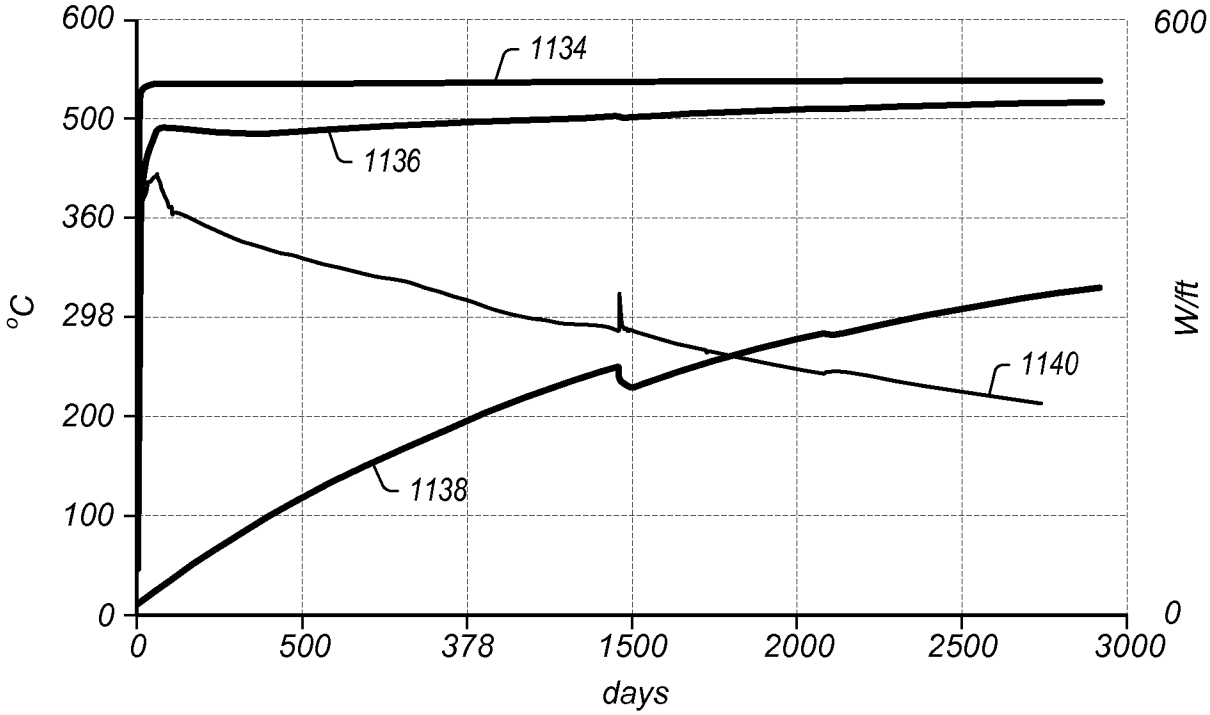


FIG. 286

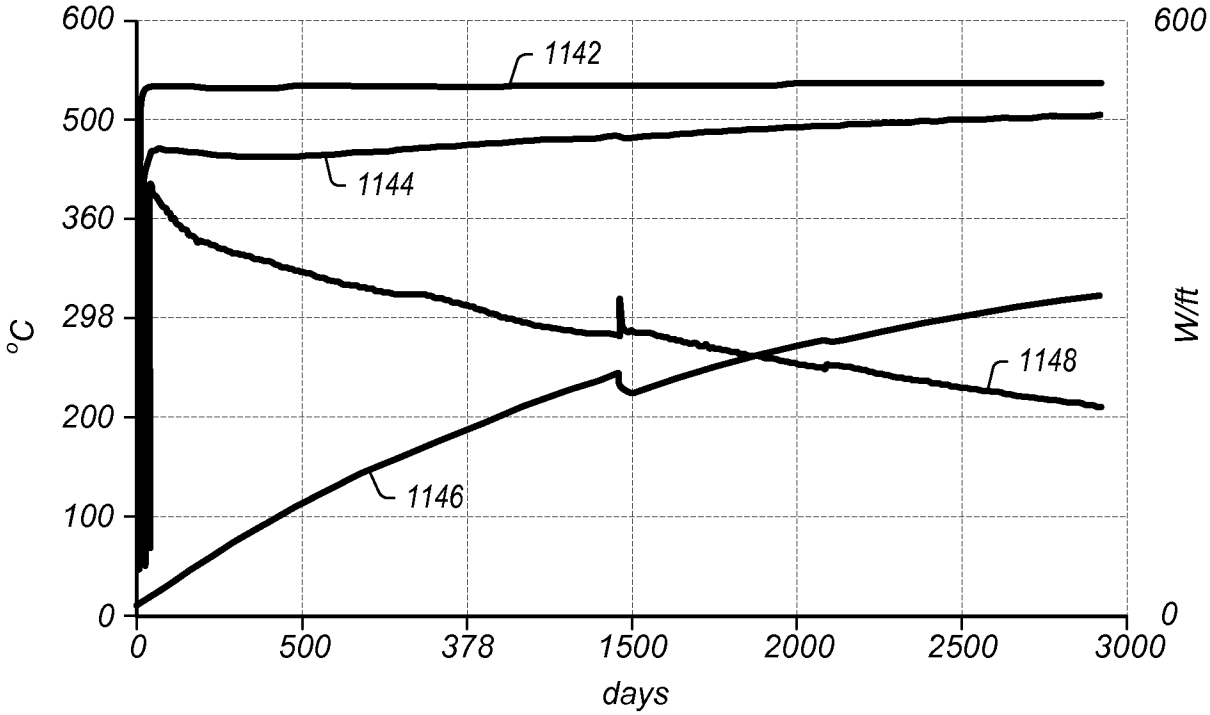


FIG. 287

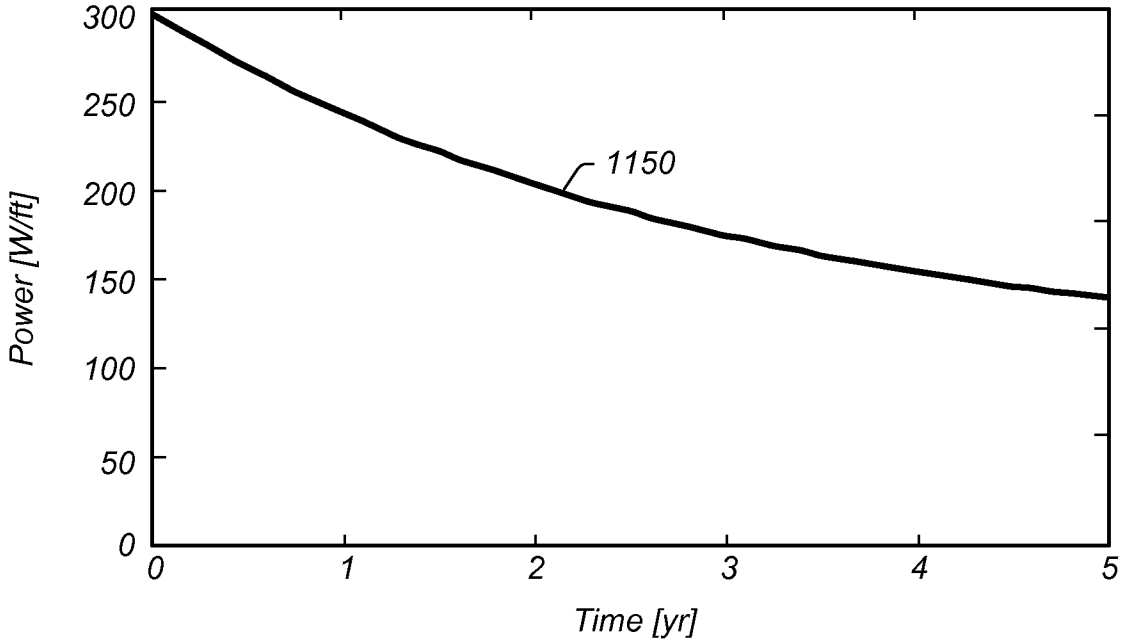


FIG. 288

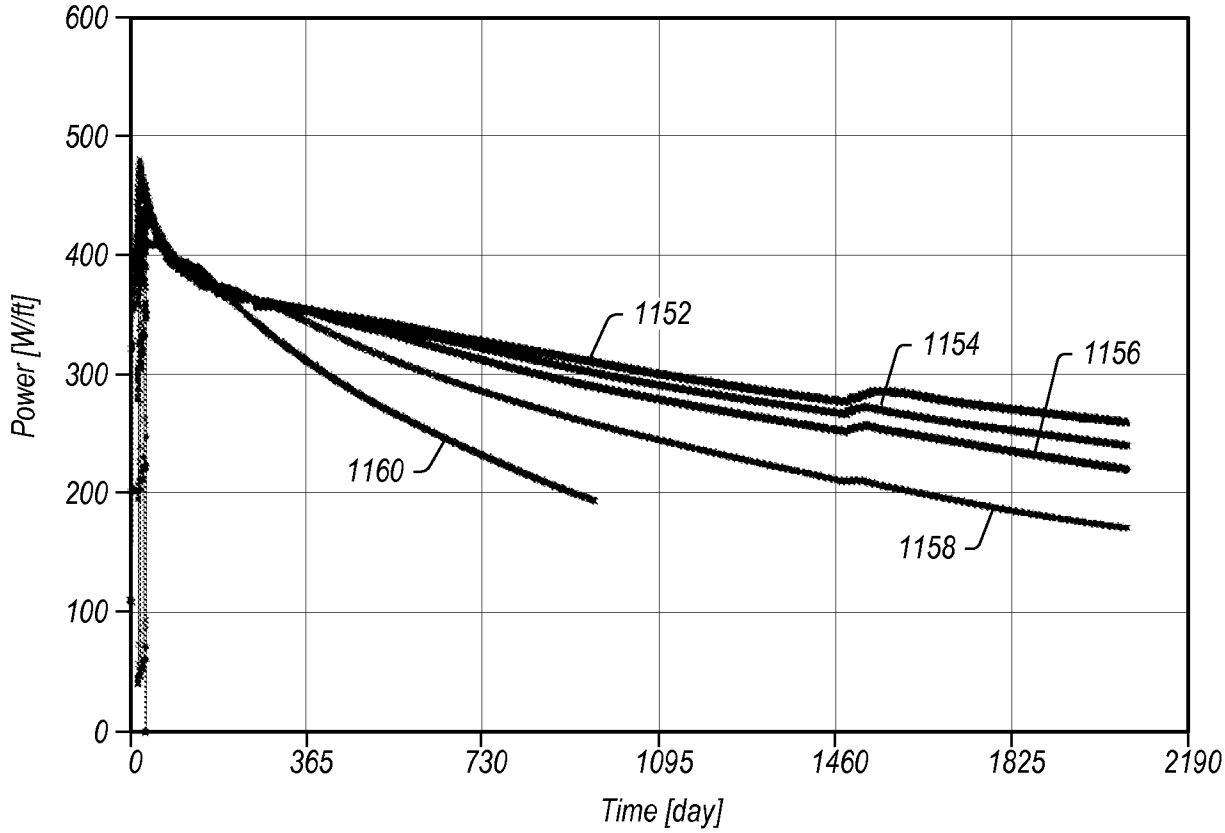


FIG. 289

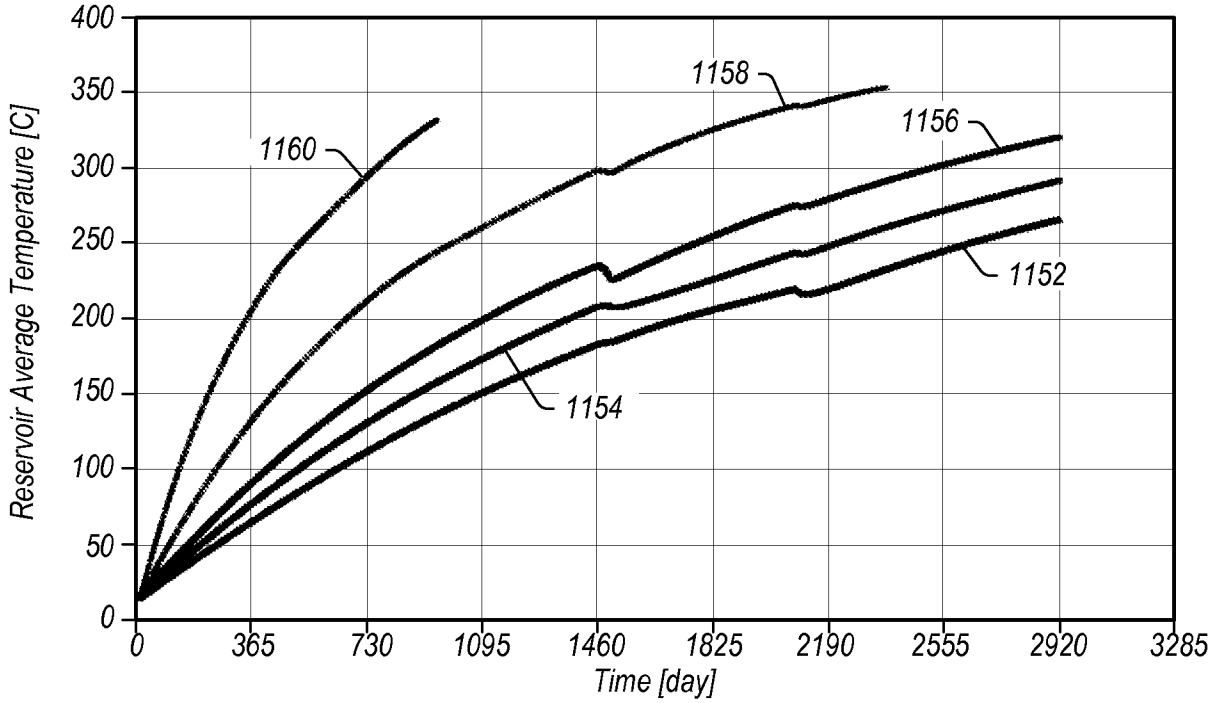


FIG. 290

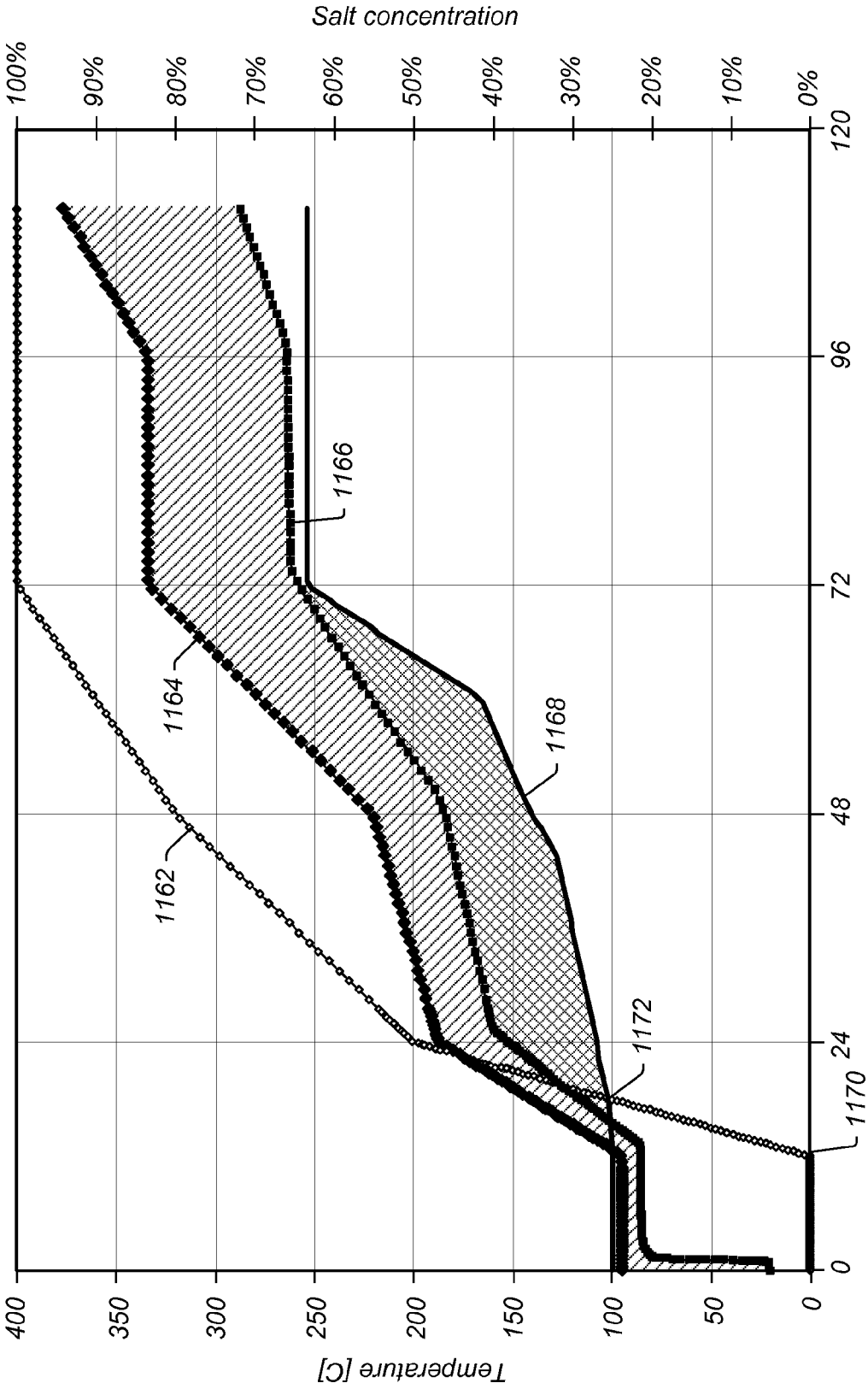

Salt concentration
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
120
96
72
48
24
0
time [hour]
400
350
300
250
200
150
100
50
0
Temperature [C]
1162
1164
1166
1168
1170
1172

FIG. 291

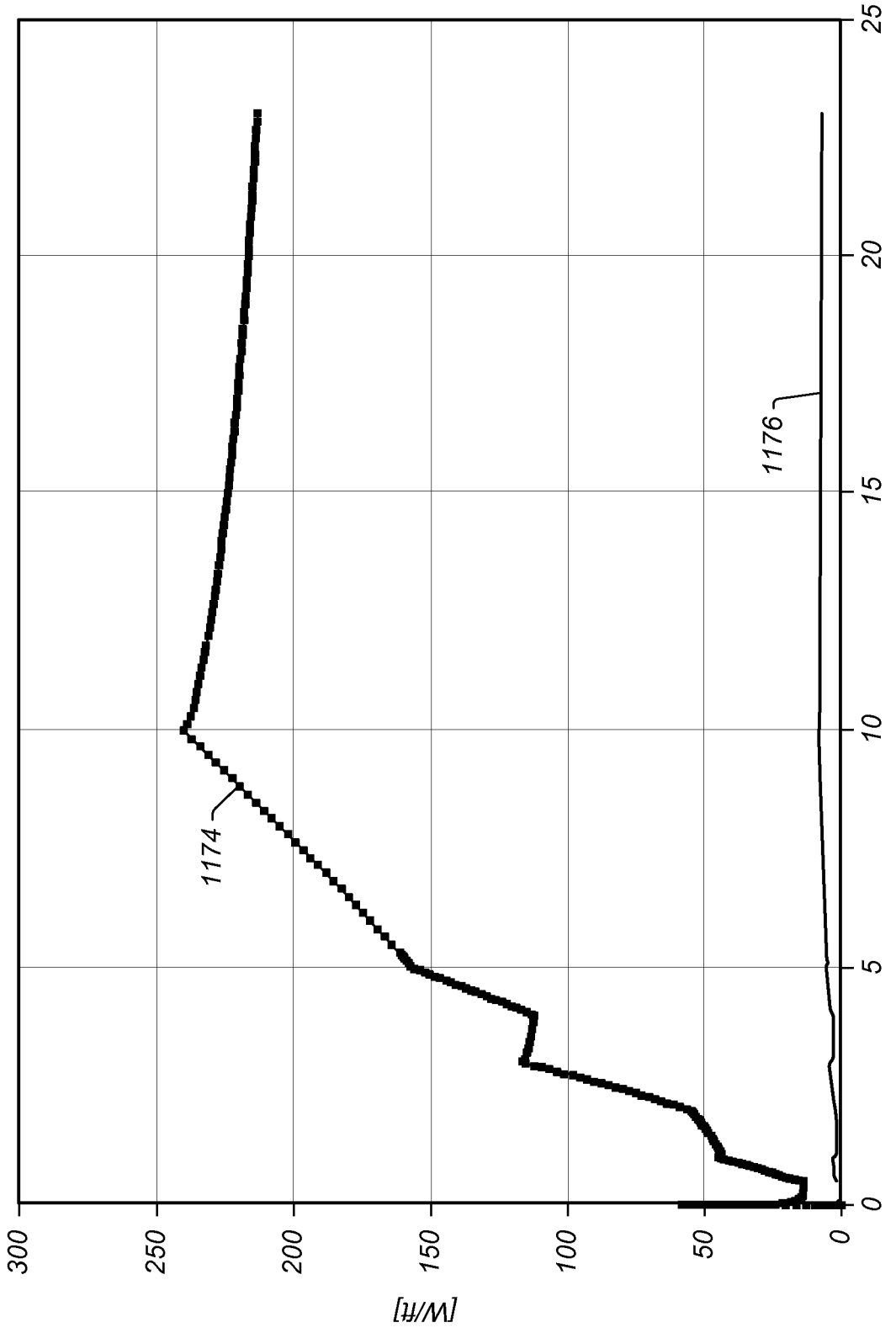


FIG. 292

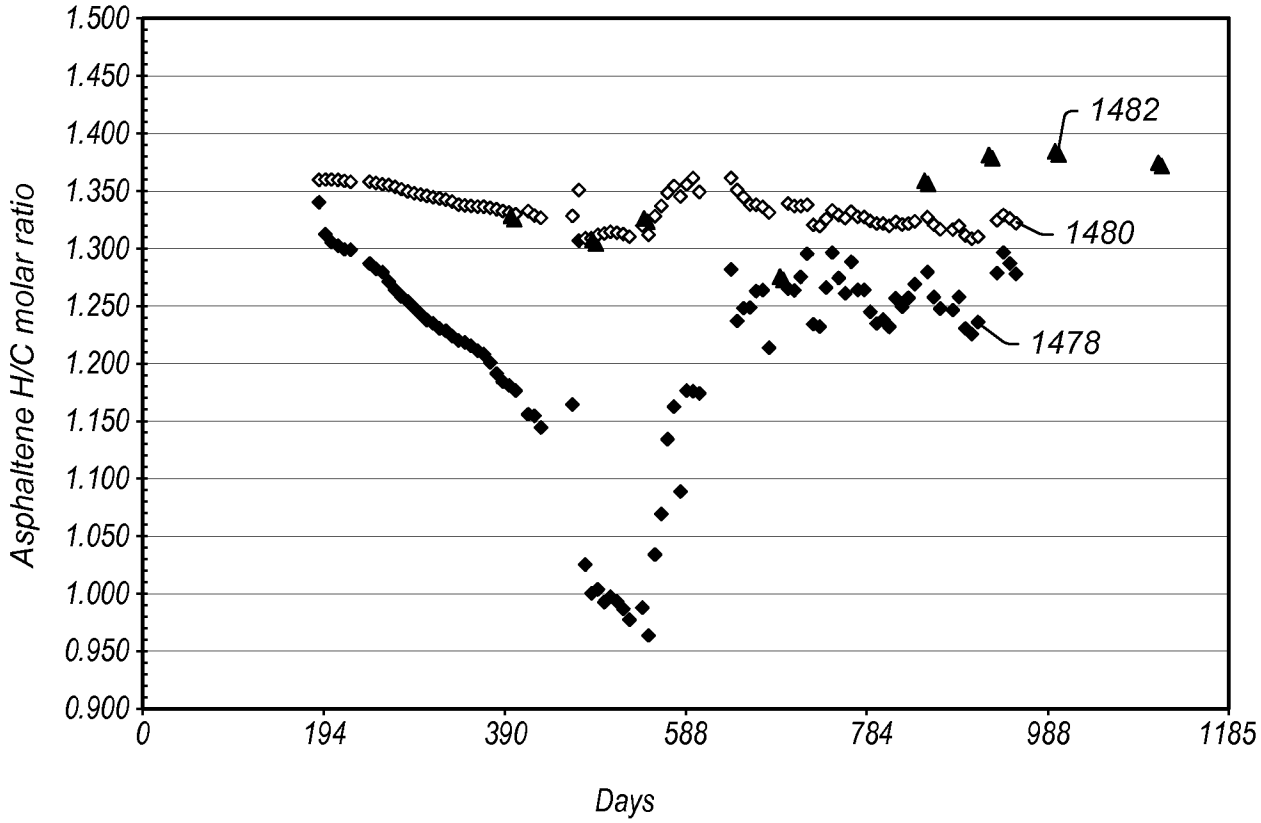

1.500
1.450
1.400
1.350
1.300
1.250
1.200
1.150
1.100
1.050
1.000
0.950
0.900
Asphaltene H/C molar ratio
0
194
390
588
784
988
1185
Days
1482
1480
1478

FIG. 293

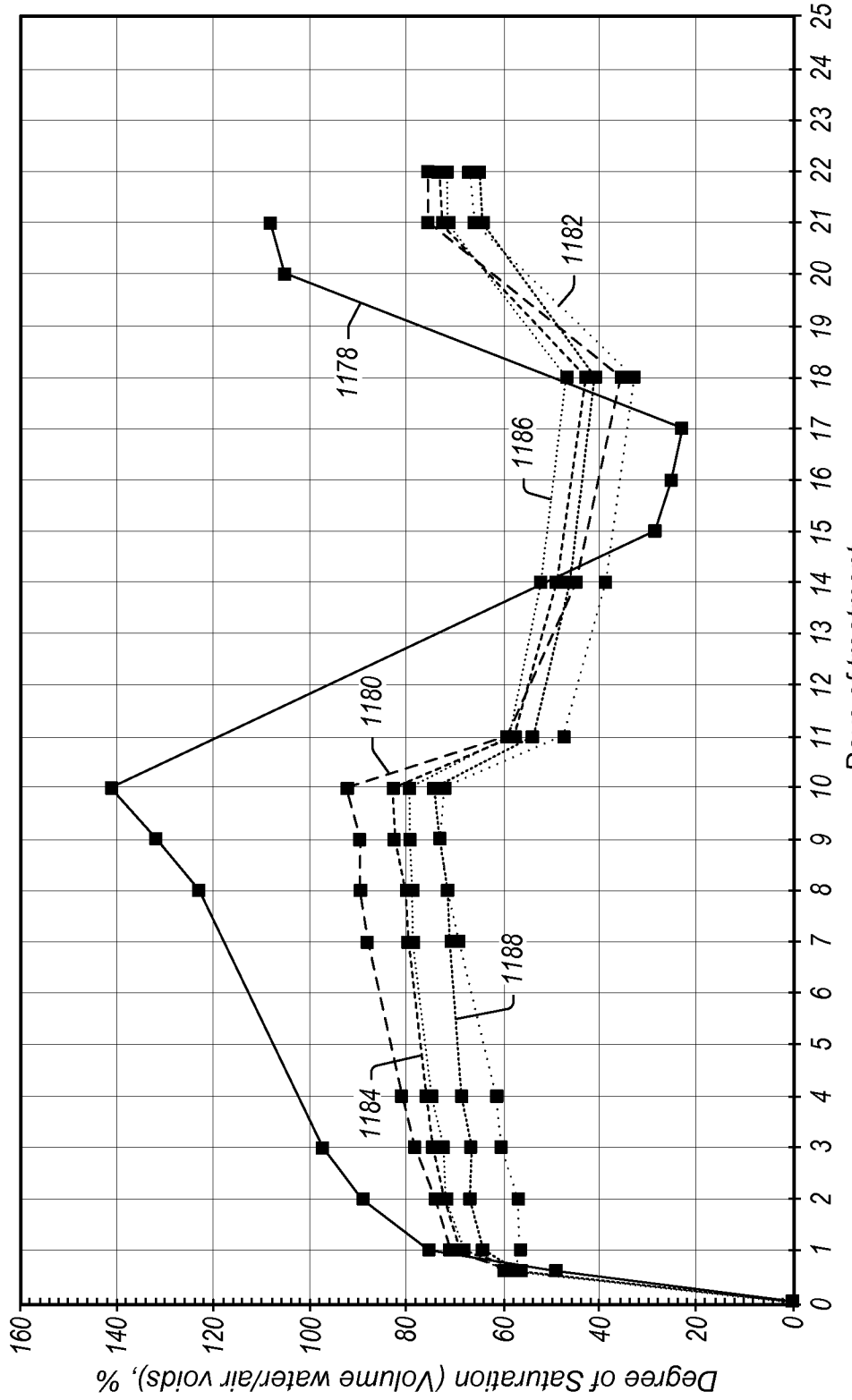

Degree of Saturation (Volume water/air voids), %
0
20
40
60
80
100
120
140
160
Days of treatment
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
1178
1180
1182
1184
1186
1188

FIG. 294

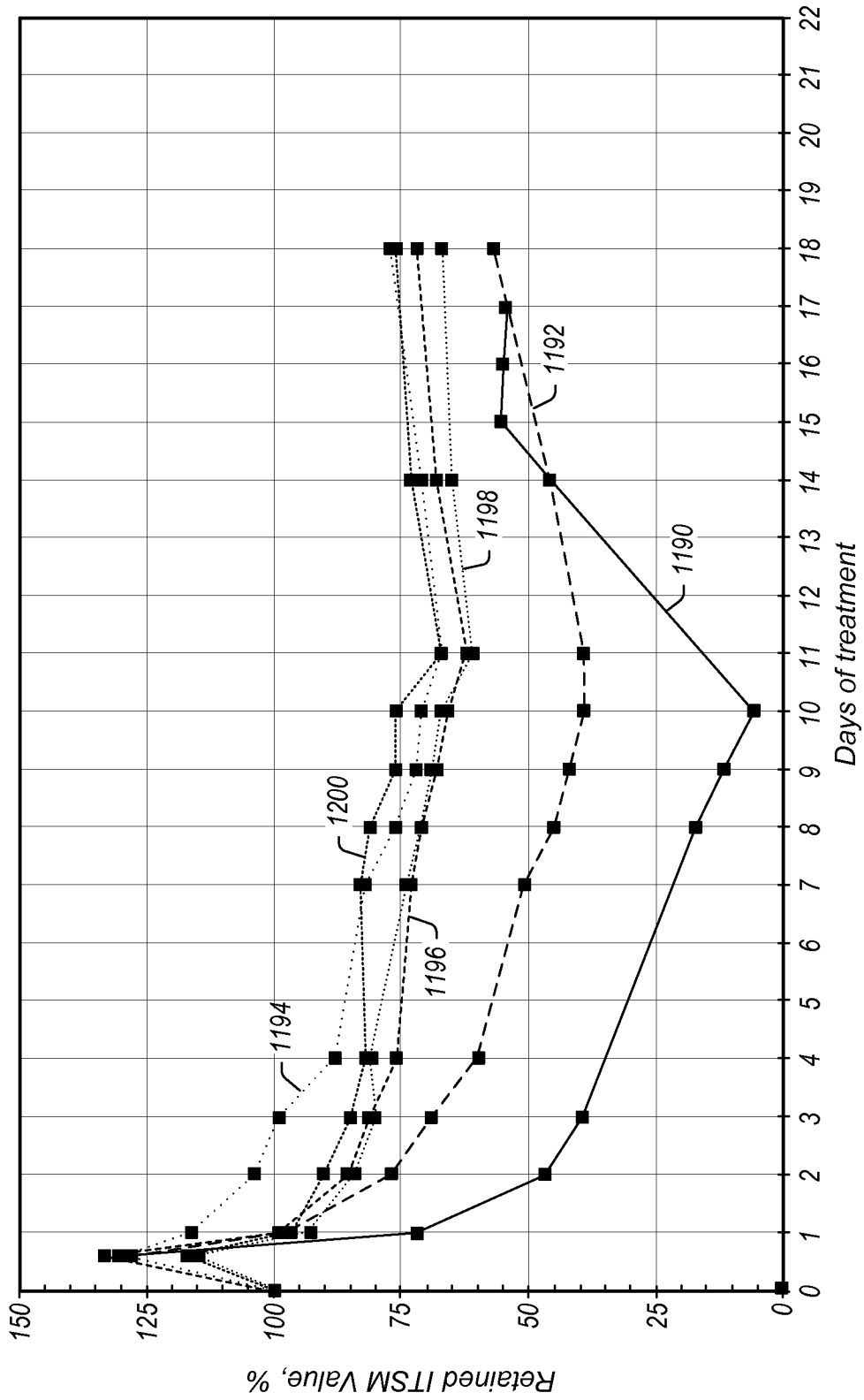

Retained ITSM Value, %
150
125
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Days of treatment
1190
1192
1194
1196
1198
1200

FIG. 295

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/30535

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - E21B 36/00 (2010.01)
USPC - 175/17
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC (8) - E21B 36/00 (2010.01)
USPC - 175/17

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 166/57,61,272.1,272.3,302,303; 175/11-16

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PUBWEST (PGPB,USPT,USOC,EPAB,JPAB) Terms - heater watts steam injection production cycle alternate heater horizontal tar sand permeability darcy wellbore shell offset lateral
Google - hydrocarbon tar sands steam injection heaters wellbores horizontal darcy; hydrocarbon tar sands steam heater wellbore

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/0071652 A1 (VINEGAR) 19 March 2009 (19.03.2009), [0750], [1191], [1229], [1237], [1247], [1271], [1276], [1281]-[1284], [1485], [1595], [1722], [1738]-[1739]; FIG. 164	1-33, 539-570
A	US 2008/0128134 A1 (MUDUNURI, ET AL.) 05 June 2008 (05.07.2008), entire document	1-33, 539-570
A	US 2008/0314593 A1 (VINEGAR, ET AL.) 25 December 2008 (25.12.2008), entire document	1-33, 539-570

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 July 2010 (22.07.2010)	09 AUG 2010
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 10/30535

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: claims 1-33, 539-570: directed to a method for treating a subsurface hydrocarbon containing formation with plural heaters and fluid injection.
Group II: claims 34-81, 571-618, 747: directed to method of recovering energy from a subsurface hydrocarbon containing formation.
Group III: claims 82-83: directed to a method of making asphalt/bitumen composition
Group IV: claims 84-105, 619-639: directed to a method of controlling the heating a subsurface hydrocarbon containing formation according to heat flux.
Group V: claims 106-127, 640-680, 697-702, 718-732: directed to a structure and method for heating a surrounding subsurface formation using a conductive heater.

(see continuation page)

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
Group I: claims 1-33, 539-570

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

(Continued from Box

Group VI: claims 128-162, 752-764: directed to a subsurface multiple fluid transfer heating system.
Group VII: claims 163-182: directed to a method for accomodating thermal expansion of subsurface heaters.
Group VIII: claims 183-246 :directed to a means for operating using a nuclear reactor to heat a subsurface formation.
Group IX: claims 247-260: directed to a dill chuck drive system and position control method therefor.
Group X: claims 261-269: directed to a method for adding tubulars to a drill string.
Group XI: claims 270-302:directed to a means for operating a mobile heater within a horizontal or inclined wellbore.
Group XII: claims 303-322: directed to an electrically insulated conductor sheath for a subsurface formation heater.
Group XIII: claims 323-334, 703-708: directed to a pressurized coiled insulated conductor heater and method for manufacturing.
Group XIV: claims 335-352, 709-717: directed to a method for installing and operating a pressurized coiled insulated conductor heater.
Group XV: claims 353-364, 915-969: directed to a method for locating and forming barrier wells.
Group XVI: claims 365-377: directed to a method for controllably heating subsurface formations based on API gravity/viscosity.
Group XVII: claims 378-438, 733-745: directed to a means for heating a subsurface formation located between two conductors.
Group XVIII: claims 439-459: directed to a method for treating a hyrdorcarbon feed stream.
Group XIX: claims 460-506, 681-696: directed to a means for coupling ends of insulated conductors.
Group XX: claims 507-538 :directed to a method for assessing a temperature in a subsurface formation.
Group XXI: claim 746: directed to a means for controlling the power supplied to a dubsurface ferromagnetic conductor.
Group XXII: claim 748: directed to a method for locating a liner to inhibit hydrocarbon ingress.
Group XXIII: claim 749: directed to a method for leak detection based on electrical resistance.
Group XXIV: claim 750: directed to a method for leak detection based on the presence of an inert gas.
Group XXV: claim 751: directed to providing a compressed gas into a pipe to remove molten salt.
Group XXVI: claims 765-769: directed to a means for inducing fractures in a subsurface formation by injecting solid salts into the formation and then melting at least a portion thereof.
Group XXVII: claims 770-808: directed to a means for controlling subsurface formation heaters based on pyrolization.
Group XXVIII: claims 809-816: directed to a method for adjustably controlling a hyrdocarbon treatment process based on P-value.
Group XXIX: claims 817-824: directed to a method for adjustably controlling a hyrdocarbon treatment process based on H/C molarity.
Group XXX: claims 825-832: directed to a method for adjustably controlling a hyrdocarbon treatment process based on naphtha/kerosene to hydrocarbon ratio.
Group XXXI claims 833-852: directed to a method for heating a hydrocarbon formation so as to generate an in situ de-asphalting fluid
Group XXXII: claims 853-862: directed to a method for locating previously inadequately treated formation portions.
Group XXXIII: claims 863-864, 890-908: directed to a method for mobilizing a sulfur containing hydrocarbon formation.
Group XXXIV: claims 865-889: directed to a method for mobilizing a bitumen containing hydrocarbon formation.
Group XXXV: claims 909-911: directed to a method for mobilizing a nitrogen containing hydrocarbon formation.
Group XXXVI: claims 912-914: directed to a method for mobilizing a dolomite containing hydrocarbon formation.

The inventions listed as Groups I - XXXVI do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

The special technical feature of each group is listed above and each is not present in the other groups.

Groups I-XXXVI share the technical features of either using one or more heaters to transfer heat to mobilize a subsurface formation via fluid injection/circulation; or the use of a heat transfer fluid in combination with insulated conductors . However, these shared technical features do not represent a contribution over the disclosed Applicant Admitted Prior Art (AAPA) at para [0006]-[0010] or US 2009/0078461 A1 (Mansure et al.) at para [0313], [0314]). As such features were known at the time, as evidenced by the teachings of AAPA and Mansure, these cannot be considered special technical features that would otherwise unify the groups.

Groups I-XXXVI therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.