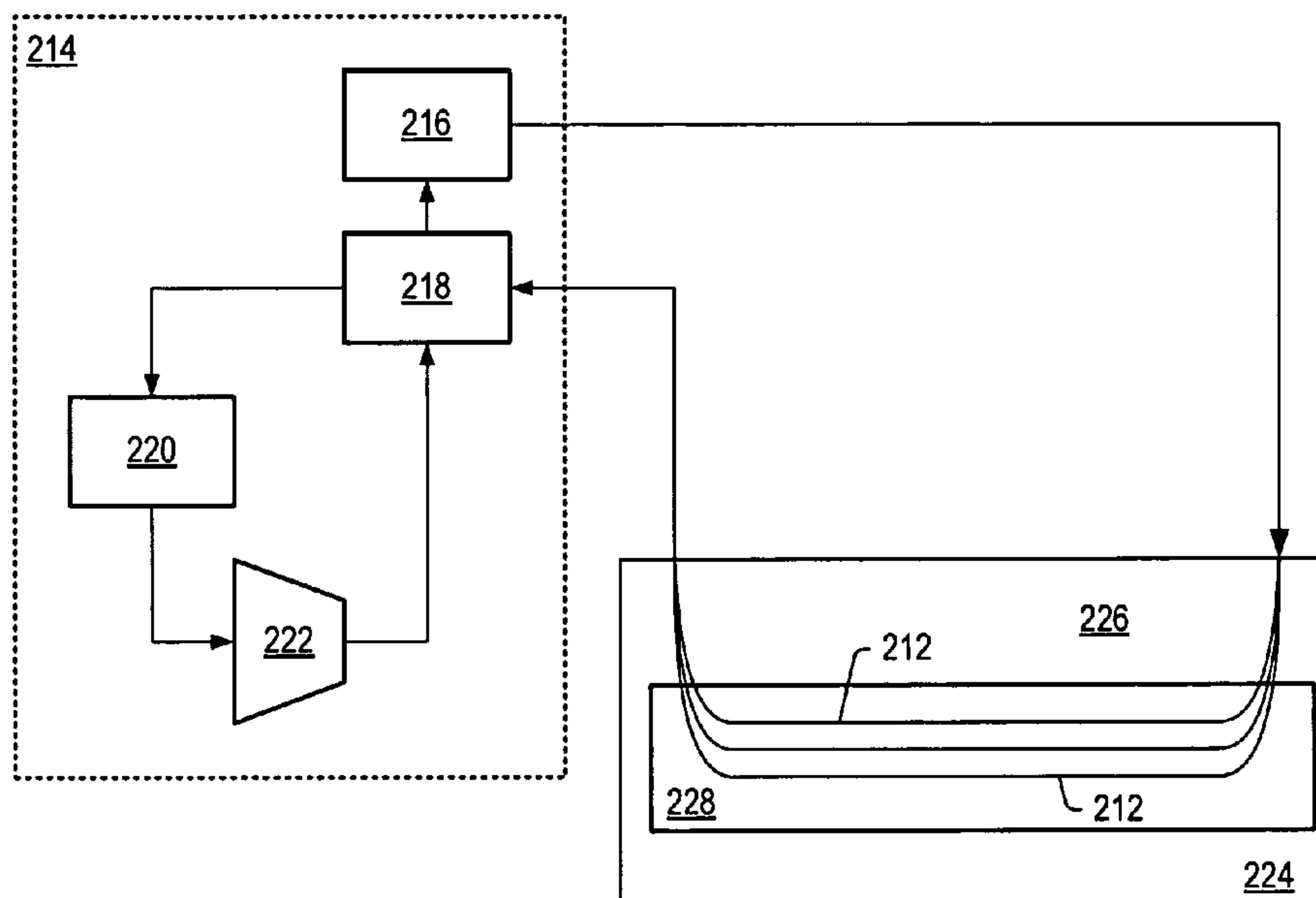




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(54) **Titre : PROCÉDE DE TRAITEMENT THERMIQUE <I>IN SITU</I> UTILISANT UN SYSTÈME DE CHAUFFAGE EN CYCLE FERME**
 (54) **Title: IN SITU HEAT TREATMENT PROCESS UTILIZING A CLOSED LOOP HEATING SYSTEM**



(57) **Abrégé/Abstract:**

Systems and methods for an in situ heat treatment process that utilizes a circulation system to heat one or more treatment areas are described herein. The circulation system may use a heated liquid heat transfer fluid that passes through piping in the formation to transfer heat to the formation. In some embodiments, the piping may be positioned in at least two of the wellbores.

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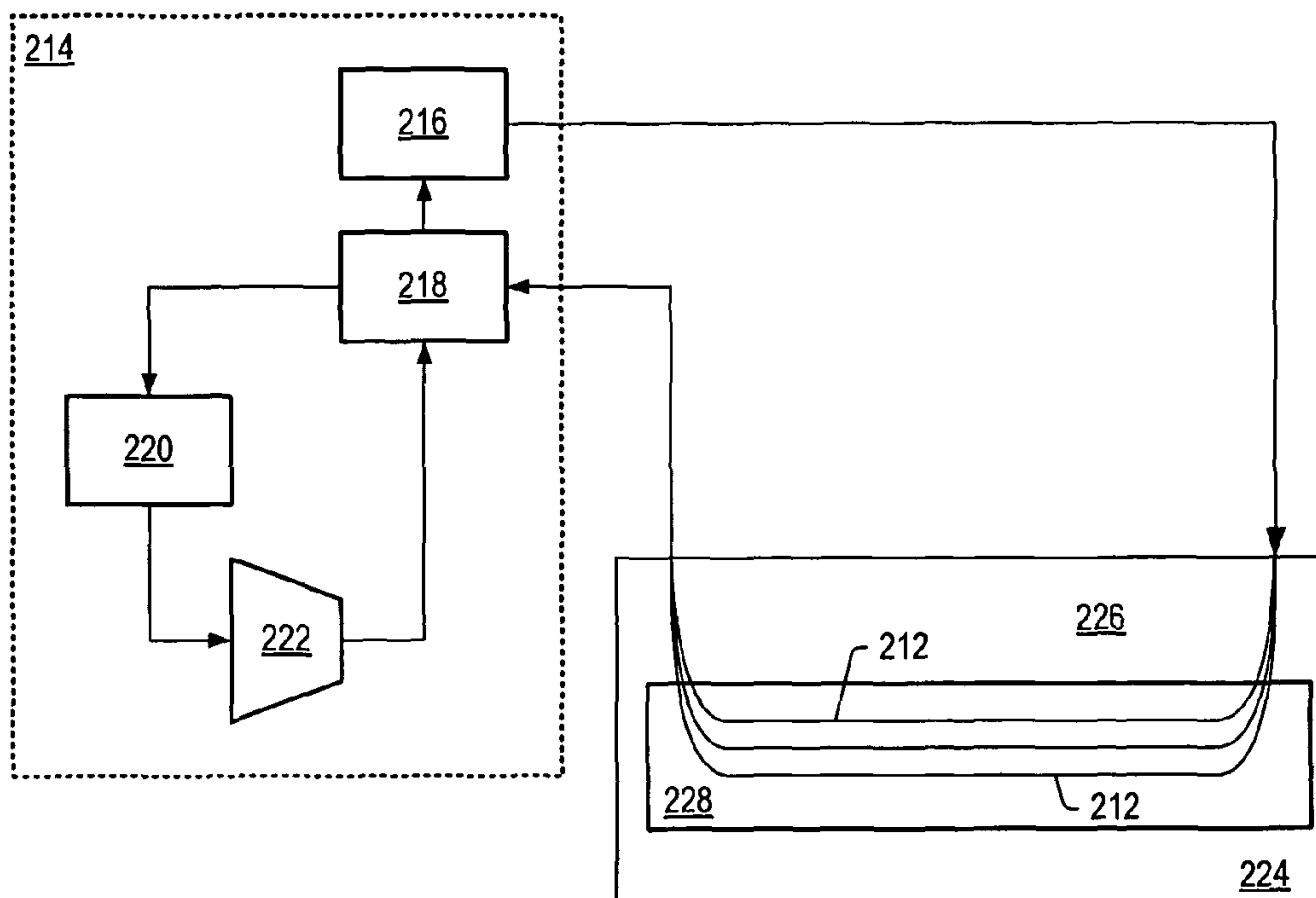
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(54) Title: IN SITU HEAT TREATMENT PROCESS UTILIZING A CLOSED LOOP HEATING SYSTEM



(57) Abstract: Systems and methods for an in situ heat treatment process that utilizes a circulation system to heat one or more treatment areas are described herein. The circulation system may use a heated liquid heat transfer fluid that passes through piping in the formation to transfer heat to the formation. In some embodiments, the piping may be positioned in at least two of the wellbores.

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**IN SITU HEAT TREATMENT PROCESS UTILIZING
A CLOSED LOOP HEATING SYSTEM**

BACKGROUND

5 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. In particular, certain embodiments relate to using a closed loop circulation system for heating a portion of the formation during an in situ
10 conversion process.

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
15 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. Chemical and/or physical properties of hydrocarbon material in a subterranean formation may need to be changed to allow
20 hydrocarbon material to be more easily removed from the subterranean formation. 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. 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
25 characteristics similar to liquid flow.

[0003] WO/2006/116096 to Fowler et al., discloses methods and system for heating treatment areas in a formation using heat transfer from gas circulated through the system and/or from resistive heating from the piping that the circulated gas passes through. The piping may be made of a ferromagnetic material.

30 [0004] Circulating gas through piping to heat the treatment area may require relative large diameter piping to accommodate the volume of gas needed to heat the treatment area. Thus, there is a need to improve circulation systems for heating treatment areas.

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SUMMARY

[0005] Embodiments described herein generally relate to systems and/or methods of producing hydrocarbons, hydrogen, and/or other products from various subsurface formations such as hydrocarbon containing formations using liquid heat transfer fluid passing through piping to heat one or more treatment areas in the formation.

[0006] In some embodiments, an in situ heat treatment system for producing hydrocarbons from a subsurface formation includes a plurality of wellbores in the formation; piping positioned in at least two of the wellbores; a fluid circulation system coupled to the piping; and a heat supply configured to heat a liquid heat transfer fluid circulated by the circulation system through the piping to heat the temperature of the formation to temperatures that allow for hydrocarbon production from the formation.

[0006a] According to an aspect, there is provided an in situ heat treatment system for producing hydrocarbons from a subsurface formation, comprising: a plurality of wellbores in the formation; piping positioned in at least two of the wellbores; a fluid circulation system coupled to the piping; a heat supply configured to heat a liquid heat transfer fluid circulated by the circulation system through the piping to heat the formation to temperatures that allow for hydrocarbon production from the formation; and one or more electrical heaters coupled to the piping configured to initially heat the piping to a temperature above a solidification temperature of the liquid heat transfer fluid.

[0007] In some embodiments, a method of heating a subsurface formation includes heating a liquid heat transfer fluid using heat exchange with a heat supply; circulating the liquid heat transfer fluid through piping in the formation to heat a portion of the formation to allow hydrocarbons to be produced from the formation; and producing hydrocarbons from the formation.

[0007a] According to an aspect, there is provided a method of heating a subsurface formation, comprising: heating a liquid heat transfer fluid using heat exchange with a heat supply, wherein the liquid heat transfer fluid is heated to a temperature sufficient to inhibit solidification of the liquid heat transfer fluid during use, and wherein the heat transfer fluid comprises one or more molten salts; circulating the liquid heat transfer fluid through piping in the formation to heat a

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portion of the formation to allow hydrocarbons to be produced from the formation; and producing hydrocarbons from the formation.

[0008] In some embodiments, a method of heating a subsurface formation includes passing a liquid heat transfer fluid from a vessel to a heat exchanger; heating the liquid heat transfer fluid to a first temperature; flowing the liquid heat transfer fluid through a heater section to a sump, wherein heat transfers from the heater section to a treatment area in the formation; gas lifting the liquid heat transfer fluid to the surface from the sump; and returning at least a portion of the liquid heat transfer fluid to the vessel.

[0008a] According to an aspect, there is provided a method of heating a subsurface formation, comprising: passing a liquid heat transfer fluid from a vessel to a heat exchanger; heating the liquid heat transfer fluid to a first temperature, wherein the first temperature is sufficient to inhibit solidification of the liquid heat transfer fluid, and wherein the heat transfer fluid comprises one or more molten salts; flowing the liquid heat transfer fluid through a heater section to a sump, wherein heat transfers from the heater section to a treatment area in the formation; and gas lifting the liquid heat transfer fluid to the surface from the sump; and returning at least a portion of the liquid heat transfer fluid to the vessel.

[0009] In further embodiments, additional features may be added to the specific embodiments described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] 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:

[0011] FIG. 1 depicts an illustration of stages of heating a hydrocarbon containing formation.

[0012] FIG. 2 shows a schematic view of an embodiment of a portion of an in situ conversion system for treating a hydrocarbon containing formation.

[0013] FIG. 3 depicts a schematic representation of a closed loop circulation system for heating a portion of a formation.

[0014] FIG. 4 depicts a plan view of wellbore entries and exits from a portion of a formation to be heated using a closed loop circulation system.

5 [0015] FIG. 5 depicts a cross sectional representation of piping of a circulation system with an insulated conductor heater positioned in the piping.

[0016] FIG. 6 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.

10 [0017] FIG. 7 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.

[0018] FIG. 8 depicts a schematic representation of an embodiment of an in situ heat treatment system that uses a nuclear reactor.

[0019] FIG. 9 depicts an elevational view of an in situ heat treatment system using pebble bed reactors.

15 [0020] FIG. 10 depicts a schematic representation of an embodiment of a downhole oxidizer assembly.

[0021] 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.

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DETAILED DESCRIPTION

[0022] 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.

30 [0023] “Alternating current (AC)” refers to a time-varying current that reverses direction substantially sinusoidally. AC produces skin effect electricity flow in a ferromagnetic conductor.

[0024] “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.

[0025] A “formation” includes one or more hydrocarbon containing layers, one or more non-hydrocarbon layers, an overburden, and/or an underburden. The “overburden” and/or the “underburden” include one or more different types of impermeable materials. For example, overburden and/or underburden may include rock, shale, mudstone, or wet/tight carbonate. In some embodiments of in situ conversion 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 conversion 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 conversion process. In some cases, the overburden and/or the underburden may be somewhat permeable.

[0026] “Formation fluids” refer to fluids present in a formation and may include pyrolyzation fluid, synthesis gas, mobilized hydrocarbon, 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 formation fluids removed from the formation.

[0027] 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 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 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 heater that provides heat to a zone proximate and/or surrounding a heating location such as a heater well.

[0028] 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.

[0029] “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.

[0030] 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.

[0031] 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.

[0032] “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 (for example, magnesium oxide).

[0033] “Modulated direct current (DC)” refers to any substantially non-sinusoidal time-varying current that produces skin effect electricity flow in a ferromagnetic conductor.

[0034] “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
5 substances by heat alone. Heat may be transferred to a section of the formation to cause pyrolysis. In some formations, portions of the formation and/or other materials in the formation may promote pyrolysis through catalytic activity.

[0035] “Pyrolyzation fluids” or “pyrolysis products” refers to fluid produced substantially during pyrolysis of hydrocarbons. Fluid produced by pyrolysis reactions may mix with
10 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.

[0036] “Superposition of heat” refers to providing heat from two or more heat sources to a
15 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.

[0037] “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.
20 Synthesis gas may be used for synthesizing a wide range of compounds.

[0038] “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
25 example, “chopped”) DC (direct current) powered electrical resistance heaters.

[0039] “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.

[0040] “Thermally conductive fluid” includes fluid that has a higher thermal conductivity
30 than air at standard temperature and pressure (STP) (0 °C and 101.325 kPa).

[0041] “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).

[0042] 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." 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".

[0043] Hydrocarbons in formations may be treated in various ways to produce many different products. In certain embodiments, hydrocarbons in formations are treated in stages. FIG. 1 depicts an illustration of stages of heating the hydrocarbon containing formation. FIG. 1 also depicts an example of yield ("Y") in barrels of oil equivalent per ton (y axis) of formation fluids from the formation versus temperature ("T") of the heated formation in degrees Celsius (x axis).

[0044] Desorption of methane and vaporization of water occurs during stage 1 heating. Heating of the formation through stage 1 may be performed as quickly as possible. When the hydrocarbon containing formation is initially heated, hydrocarbons in the formation desorb adsorbed methane. The desorbed methane may be produced from the formation. If the hydrocarbon containing formation is heated further, water in the hydrocarbon containing formation is vaporized. Water may occupy, in some hydrocarbon containing formations, between 10% and 50% of the pore volume in the formation. In other formations, water occupies larger or smaller portions of the pore volume. Water typically is vaporized in a formation between 160 °C and 285 °C at pressures of 600 kPa absolute to 7000 kPa absolute. In some embodiments, the vaporized water produces wettability changes in the formation and/or increased formation pressure. The wettability changes and/or increased pressure may affect pyrolysis reactions or other reactions in the formation. In certain embodiments, the vaporized water is produced from the formation. In other embodiments, the vaporized water is used for steam extraction and/or distillation in the

formation or outside the formation. Removing the water from and increasing the pore volume in the formation increases the storage space for hydrocarbons in the pore volume. [0045] In certain embodiments, after stage 1 heating, the formation is heated further, such that a temperature in the formation reaches (at least) an initial pyrolyzation temperature (such as a temperature at the lower end of the temperature range shown as stage 2). Hydrocarbons in the formation may be pyrolyzed throughout stage 2. A pyrolysis temperature range varies depending on the types of hydrocarbons in the formation. The pyrolysis temperature range may include temperatures between 250 °C and 900 °C. The pyrolysis temperature range for producing desired products may extend through only a portion of the total pyrolysis temperature range. In some embodiments, the pyrolysis temperature range for producing desired products may include temperatures between 250 °C and 400 °C or temperatures between 270 °C and 350 °C. If a temperature of hydrocarbons in the formation is slowly raised through the temperature range from 250 °C to 400 °C, production of pyrolysis products may be substantially complete when the temperature approaches 400 °C. Average temperature of the hydrocarbons may be raised at a rate of less than 5 °C per day, less than 2 °C per day, less than 1 °C per day, or less than 0.5 °C per day through the pyrolysis temperature range for producing desired products. Heating the hydrocarbon containing formation with a plurality of heat sources may establish thermal gradients around the heat sources that slowly raise the temperature of hydrocarbons in the formation through the pyrolysis temperature range. [0046] The rate of temperature increase through the pyrolysis temperature range for desired products may affect the quality and quantity of the formation fluids produced from the hydrocarbon containing formation. Raising the temperature slowly through the pyrolysis temperature range for desired products may inhibit mobilization of large chain molecules in the formation. Raising the temperature slowly through the pyrolysis temperature range for desired products may limit reactions between mobilized hydrocarbons that produce undesired products. Slowly raising the temperature of the formation through the pyrolysis temperature range for desired products may allow for the production of high quality, high API gravity hydrocarbons from the formation. Slowly raising the temperature of the formation through the pyrolysis temperature range for desired products may allow for the removal of a large amount of the hydrocarbons present in the formation as hydrocarbon product.

[0047] In some in situ conversion 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. 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 the desired temperature. The heated portion of the formation is maintained substantially at the desired temperature until pyrolysis declines such that production of desired formation fluids from the formation becomes uneconomical. Parts of the formation that are subjected to pyrolysis may include regions brought into a pyrolysis temperature range by heat transfer from only one heat source.

[0048] In certain embodiments, formation fluids including pyrolyzation fluids are produced from the formation. As the temperature of the formation increases, the amount of condensable hydrocarbons in the produced formation fluid may decrease. At high temperatures, the formation may produce mostly methane and/or hydrogen. If the hydrocarbon containing formation is heated throughout the entire pyrolysis range, the formation may produce only small amounts of hydrogen towards an upper limit of the pyrolysis range. After all of the available hydrogen is depleted, a minimal amount of fluid production from the formation will typically occur.

[0049] After pyrolysis of hydrocarbons, a large amount of carbon and some hydrogen may still be present in the formation. A significant portion of carbon remaining in the formation can be produced from the formation in the form of synthesis gas. Synthesis gas generation may take place during stage 3 heating depicted in FIG. 1. Stage 3 may include heating a hydrocarbon containing formation to a temperature sufficient to allow synthesis gas generation. 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. The temperature of the heated portion of the formation when the synthesis gas generating fluid is introduced to the formation determines the composition of synthesis gas produced in the formation. The generated synthesis gas may be removed from the formation through a production well or production wells.

[0050] Total energy content of fluids produced from the hydrocarbon containing formation may stay relatively constant throughout pyrolysis and synthesis gas generation. During

pyrolysis at relatively low formation temperatures, a significant portion of the produced fluid may be condensable hydrocarbons that have a high energy content. At higher pyrolysis temperatures, however, less of the formation fluid may include condensable hydrocarbons. More non-condensable formation fluids may be produced from the formation. Energy content per unit volume of the produced fluid may decline slightly during generation of predominantly non-condensable formation fluids. During synthesis gas generation, energy content per unit volume of produced synthesis gas declines significantly compared to energy content of pyrolyzation fluid. The volume of the produced synthesis gas, however, will in many instances increase substantially, thereby compensating for the decreased energy content.

[0051] FIG. 2 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.

[0052] Freeze wells may be used to establish a low temperature zone around all or a portion of a treatment area. 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 a frozen barrier.

[0053] In the embodiment depicted in FIG. 2, 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.

[0054] 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.

10 [0055] 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.

[0056] 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 and above) in the production well, and/or (5) increase formation permeability at or proximate the production well.

[0057] 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 increased fluid generation and vaporization of water. Controlling 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, or at monitor wells.

[0058] In some hydrocarbon containing formations, production of hydrocarbons from the formation is inhibited until at least some hydrocarbons in the formation have been
5 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 20°, 30°, or 40°. Inhibiting production until at least some hydrocarbons are pyrolyzed may increase conversion of heavy hydrocarbons to light hydrocarbons. Inhibiting initial production may minimize the production of heavy hydrocarbons from the
10 formation. Production of substantial amounts of heavy hydrocarbons may require expensive equipment and/or reduce the life of production equipment.

[0059] After 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 formation fluid produced, to control a percentage of condensable fluid as compared to non-
15 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.

[0060] In some in situ heat treatment process embodiments, pressure in the formation may
20 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 facilitate vapor phase production of fluids from the formation. Vapor phase production may allow for a reduction in size of collection conduits used to transport fluids produced from the
25 formation. 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.

[0061] Maintaining increased pressure in a heated portion of the formation may
surprisingly allow for production of large quantities of hydrocarbons of increased quality
30 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.

[0062] 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.

[0063] In some in situ heat treatment process embodiments, a circulation system is used to heat the formation. The circulation system may be a closed loop circulation system. FIG. 3 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 not as deep in the ground. The hydrocarbons may be in formations that extend lengthwise up to 500 m, 750 m, 1000 m, or more. The circulation system may become economically viable in formations where the length of the hydrocarbon containing formation to be treated is long compared to the thickness of the overburden. The ratio of the hydrocarbon formation extent to be heated by heaters to the overburden thickness may be at least 3, at least 5, or at least 10. The heaters of the circulation system may be positioned relative to adjacent heaters so 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.

[0064] In some embodiments, heaters 212 may be 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 212. Heaters 212 are connected to heat transfer fluid circulation system 214 by piping. Gas at high pressure may be used as the heat transfer fluid in the closed loop circulation system. In some embodiments, the heat transfer fluid is carbon dioxide. Carbon dioxide is chemically stable at the required temperatures and pressures and has a relatively high molecular weight that results in a high volumetric heat capacity. Other fluids such as steam, air, helium and/or nitrogen may also be used. The pressure of the heat transfer fluid entering the formation may be 3000 kPa or higher. The use of high pressure heat transfer fluid allows the heat transfer fluid to have a greater density, and therefore a greater capacity to transfer heat. Also, the pressure drop across the heaters is less for a system where the heat transfer fluid enters the heaters at a first pressure for a given mass flow rate than when the heat transfer fluid enters the heaters at a second pressure at the same mass flow rate when the first pressure is greater than the second pressure.

[0065] In some embodiments, a liquid heat transfer fluid is used as the heat transfer fluid. The liquid heat transfer fluid may be a natural or synthetic oil, molten metal, molten salt, or other type of high temperature heat transfer fluid. A liquid heat transfer fluid may allow for smaller diameter piping and reduced pumping/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 a 10 mil thick nickel liner. The 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 may also be used. Corrosion of nickel by the molten fluoride salt may be less than 1 mil per year at a temperature of about 840 °C.

[0066] Heat transfer fluid circulation system 214 may include heat supply 216, first heat exchanger 218, second heat exchanger 220, and compressor 222. Heat supply 216 heats the heat transfer fluid to a high temperature. Heat supply 216 may be a furnace, solar collector, chemical reactor, nuclear reactor, fuel cell exhaust heat, or other high temperature source able to supply heat to the heat transfer fluid. In the embodiment depicted in FIG. 3, heat supply 216 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 216 heats the heat transfer fluid to a temperature of about 820 °C. The heat transfer fluid flows from heat supply 216 to heaters 212. Heat transfers from heaters 212 to formation 224 adjacent to the heaters. The temperature of the heat transfer fluid exiting formation 224 may be in a range from 350 °C to 580 °C, from 400 °C to 530 °C, or from 450 °C to 500 °C. In an embodiment, the temperature of the heat transfer fluid exiting formation 224 is 480 °C. The metallurgy of the piping used to form heat transfer fluid circulation system 214 may be varied to significantly reduce costs of the piping. High temperature steel may be used from heat supply 216 to a point where the temperature is sufficiently low so that less expensive steel can be used from that point to first heat exchanger 218. Several different steel grades may be used to form the piping of heat transfer fluid circulation system 214.

[0067] Heat transfer fluid from heat supply 216 of heat transfer fluid circulation system 214 passes through overburden 226 of formation 224 to hydrocarbon layer 228. Portions of heaters 212 extending through overburden 226 may be insulated. In some embodiments, the insulation or part of the insulation is a polyimide insulating material. Inlet portions of heaters 212 in hydrocarbon layer 228 may have tapering insulation to reduce overheating of the hydrocarbon layer near the inlet of the heater into the hydrocarbon layer.

[0068] In some embodiments, the diameter of the pipe in overburden 226 may be smaller than the diameter of pipe through hydrocarbon layer 228. The smaller diameter pipe through overburden 226 may allow for less heat transfer to the overburden. Reducing the amount of heat transfer to overburden 226 reduces the amount of cooling of the heat transfer fluid supplied to pipe adjacent to hydrocarbon layer 228. The increased heat transfer in the smaller diameter pipe due to increased velocity of heat transfer fluid through the small 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.

[0069] After exiting formation 224, the heat transfer fluid passes through first heat exchanger 218 and second heat exchanger 220 to compressor 222. First heat exchanger 218 transfers heat between heat transfer fluid exiting formation 224 and heat transfer fluid exiting compressor 222 to raise the temperature of the heat transfer fluid that enters heat supply 216 and reduce the temperature of the fluid exiting formation 224. Second heat exchanger 220 further reduces the temperature of the heat transfer fluid before the heat transfer fluid enters compressor 222.

[0070] In some embodiments, a liquid heat transfer fluid may be used instead of a gas heat transfer fluid. The compressor banks represented by compressor 222 in FIG. 3 may be replaced by pumps or other liquid moving devices.

[0071] FIG. 4 depicts a plan view of an embodiment of wellbore openings in the formation that is to be heated using the circulation system. Heat transfer fluid entries 230 into formation 224 alternate with heat transfer fluid exits 232. Alternating heat transfer fluid entries 230 with heat transfer fluid exits 232 may allow for more uniform heating of the hydrocarbons in formation 224.

[0072] In some embodiments, piping 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 initially 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 about a year, about six months, about three months, about two months or any other desired time interval.

[0073] In some embodiments, the circulation system may be used in conjunction with electrical heating. In some embodiments, at least a portion of the pipe in the U-shaped wellbores adjacent to portions of the formation that are to be heated is made of a ferromagnetic material. For example, the piping adjacent to a layer or layers of the formation to be heated is made of 9% to 13% chromium steel, such as 410 stainless steel. The pipe may be a temperature limited heater when time varying electric current is applied to the piping. The time varying electric current may resistively heat the piping, which heats the formation and the material in the piping. In some embodiments, direct electric current may be used to resistively heat the pipe, which heats the formation. In some embodiments, the material used to form the pipe in the U-shaped wellbore does not include ferromagnetic material. Direct or time varying current may be used to resistively heat the pipe, which heats the formation.

[0074] In some embodiments, one or more insulated conductors are placed in the piping. Electrical current may be supplied to the insulated conductors to resistively heat at least a portion of the insulated conductors. Heated insulated conductors may provide heat to the contents of the piping and the piping. The piping heated by the insulated conductor may heat adjacent formation. FIG. 5 depicts insulated conductor 233 positioned in heater 212.

Heater 212 is piping of the circulation system positioned in the formation. In some embodiments, one or more insulated conductors may be strapped to the piping.

[0075] In some embodiments, the circulation system is used to heat the formation to a first temperature, and electrical energy is used to maintain the temperature of the formation and/or heat the formation to higher temperatures. The first temperature may be sufficient to vaporize aqueous formation fluid in the formation. The first temperature may be at most 200 °C, at most 300 °C, at most 350 °C, or at most 400 °C. Using the circulation system to heat the formation to the first temperature allows the formation to be dry when electricity is used to heat the formation. Heating the dry formation may minimize electrical current leakage into the formation.

[0076] In some embodiments, the circulation system and electrical heating may be used to heat the formation to a first temperature. The formation may be maintained, or the temperature of the formation may be increased from the first temperature, using the circulation system and/or electrical heating. In some embodiments, the formation may be raised to the first temperature using electrical heating, and the temperature may be maintained and/or increased using the circulation system. Economic factors, available electricity, availability of fuel for heating the heat transfer fluid, and other factors may be used to determine when electrical heating and/or circulation system heating are to be used.

[0077] In some embodiments, electrical heating is used to raise the temperature of the piping to a desired temperature. The desired temperature may be a temperature higher than a temperature needed to maintain the heat transfer fluid (for example, a molten metal or a molten salt) in a liquid phase. The electrical heating may inhibit plugging of the piping and allow the heat transfer to flow through the piping. Electrical heating may be discontinued when the circulation system is able to maintain the heat transfer fluid as a liquid without additional heat input from the electrical heating. For example, electrical heating may initially be used when the system is initiated. The electrical heating may heat the piping so that the liquid heat transfer fluid does not solidify in the piping. After the formation adjacent to the piping becomes hotter than the melting temperature of the heat transfer fluid, the electrical heating may be discontinued. If a shut down or other problem occurs that might result in solidification of heat transfer fluid in the piping, electrical heating may be resumed.

[0078] FIG. 3 depicts an embodiment of a circulation system. In certain embodiments, the portion of heater 212 in hydrocarbon layer 228 is coupled to lead-in conductors. Lead-in

conductors may be located in overburden 226. Lead-in conductors may electrically couple the portion of heater 212 in hydrocarbon layer 228 to one or more wellheads at the surface. Electrical isolators may be located at a junction of the portion of heater 212 in hydrocarbon layer 228 with portions of heater 212 in overburden 226 so that the portions of the heater in the overburden are electrically isolated from the portion of the heater in the hydrocarbon layer.

[0079] In embodiments where the electrical heating is needed to raise the temperature of the piping to or above a desired temperature, the lead-in conductors are coupled to the piping at or near the surface so that all of the piping in the formation is heated to the desired temperature. Piping near the surface may include electrical insulation (for example, a porcelain coating) to inhibit current leakage to the formation.

[0080] In some embodiments, the lead-in conductors are placed inside of the pipe of the closed loop circulation system. In some embodiments, the lead-in conductors are positioned outside of the pipe of the closed loop circulation system. In some embodiments, the lead-in conductors are insulated conductors with mineral insulation, such as magnesium oxide. The lead-in conductors may include highly electrically conductive materials such as copper or aluminum to reduce heat losses in overburden 226 during electrical heating.

[0081] In certain embodiments, the portions of heater 212 in overburden 226 are used as lead-in conductors. The portions of heater 212 in overburden 226 may be electrically coupled to the portion of heater 212 in hydrocarbon layer 228. In some embodiments, one or more electrically conducting materials (such as copper or aluminum) are coupled (for example, cladded or welded) to the portions of heater 212 in overburden 226 to reduce the electrical resistance of the portions of the heater in the overburden. Reducing the electrical resistance of the portions of heater 212 in overburden 226 reduces heat losses in the overburden during electrical heating.

[0082] In some embodiments, the portion of heater 212 in hydrocarbon layer 228 is a temperature limited heater with a self-limiting temperature between 600 °C and 1000 °C. The portion of heater 212 in hydrocarbon layer 228 may be a 9% to 13% chromium stainless steel. For example, portion of heater 212 in hydrocarbon layer 228 may be 410 stainless steel. Time-varying current may be applied to the portion of heater 212 in hydrocarbon layer 228 so that the heater operates as a temperature limited heater.

[0083] FIG. 6 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 234 of heaters 212 may be coupled to heat transfer fluid circulation system 214 by piping. Wellheads 234 may also be coupled to electrical power supply system 236. In some embodiments, heat transfer fluid circulation system 214 is disconnected from the heaters when electrical power is used to heat the formation. In some embodiments,
 5 electrical power supply system 236 is disconnected from the heaters when heat transfer fluid circulation system 214 is used to heat the formation.

[0084] Electrical power supply system 236 may include transformer 238 and cables 240, 242. In certain embodiments, cables 240, 242 are capable of carrying high currents with low losses. For example, cables 240, 242 may be thick copper or aluminum conductors.
 10 The cables may also have thick insulation layers. In some embodiments, cable 240 and/or cable 242 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 238 to the heaters. In
 15 some embodiments, cables 240, 242 may be made of carbon nanotubes.

[0085] In some embodiments, a liquid heat transfer fluid is used to heat the treatment area. In some embodiments, the liquid heat transfer fluid is a molten salt or a molten metal. The liquid heat transfer fluid may have a low viscosity and a high heat capacity at normal operating conditions. Table 1 shows melting (T_m) and boiling temperatures (T_b) for several
 20 materials that may be used as the liquid heat transfer fluid. When the liquid heat transfer fluid is a molten metal, 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.

25

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

TIBr	460	819
TIF	326	826
ThI ₄	566	837
SnF ₂	215	850
SnI ₂	320	714
ZnCl ₂	290	732

[0086] FIG. 7 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 244 is elevated above heat exchanger 246. Heat transfer fluid from vessel 244 flows through heat transfer unit 246 to the formation by gravity drainage. In an embodiment, heat exchanger 246 is a tube and shell heat exchanger. Input stream 248 is a hot fluid (for example, helium) from nuclear reactor 250. Exit stream fluid 252 may be sent as a coolant stream to nuclear reactor 250. In some embodiments, the heat exchanger is a furnace, solar collector, chemical reactor, fuel cell, or other high temperature source able to supply heat to the liquid heat transfer fluid.

[0087] Hot heat transfer fluid from heat exchanger 246 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 226 to hydrocarbon containing layer 228 of the treatment area. The piping adjacent to overburden 226 may be insulated. Heat transfer fluid flows downwards to sump 254.

[0088] Gas lift piping may include gas supply line 256 within conduit 258. Gas supply line 256 may enter sump 254. When lift chamber 260 in sump 254 fills to a selected level with heat transfer fluid, a gas lift control system operates valves of the gas lift system so that the heat transfer fluid is lifted through the space between gas supply line 256 and conduit 258 to separator 262. Separator 262 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 262 separates the lift gas from the heat transfer fluid. The heat transfer fluid is sent to vessel 244.

[0089] Conduits 258 from sumps 254 to separator 262 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 258 and/or be strapped or otherwise coupled to the outside of the conduits. The heaters may inhibit solidification of the heat transfer fluid in conduits 258 during the gas lift from sump 254.

[0090] In some embodiments, nuclear energy may be used to heat the heat transfer fluid used in the circulation system to heat a portion of the formation. Heat supply 216 in FIG. 3 may be a pebble bed reactor or other type of nuclear reactor, such as a light water reactor. The use of nuclear energy provides a heat source with little or no carbon dioxide emissions. Also, the use of nuclear energy can be 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.

[0091] In some embodiments, a nuclear reactor may heat 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 may heat helium, and the helium may be passed through a heat exchanger to provide heat to the heat transfer fluid used to heat the formation. The pebble bed 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 pebble bed 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 fluid. Pebble bed reactor systems are available from PBMR Ltd. (Centurion, South Africa).

[0092] FIG. 8 depicts a schematic diagram of a system that uses nuclear energy to heat treatment area 264. The system may include helium system gas blower 266, nuclear reactor 268, heat exchanger units 270, and heat transfer fluid blower 272. Helium system gas blower 266 may draw heated helium from nuclear reactor 268 to heat exchanger units 270. Helium from heat exchanger units 270 may pass through helium system gas blower 266 to nuclear reactor 268. Helium from nuclear reactor 268 may be at a temperature of 900 °C to 1000 °C. Helium from helium gas blower 266 may be at a temperature of 500 °C to 600 °C. Heat transfer fluid blower 272 may draw heat transfer fluid from heat exchanger units 270 through treatment area 264. Heat transfer fluid may pass through heat transfer fluid blower 272 to heat exchanger units 270. The heat transfer fluid may be carbon dioxide. The heat transfer fluid may be at a temperature from 850 °C to 950 °C after exiting heat exchanger units 270.

[0093] In some embodiments, the system may include auxiliary power unit 274. In some embodiments, auxiliary power unit 274 generates power by passing the helium from heat exchanger units 270 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 268. In some embodiments, auxiliary power unit 274 generates power using a heat transfer fluid (for example, ammonia or aqua ammonia). Helium from heat exchanger units 270 is sent to additional heat exchanger units to transfer heat to the heat transfer fluid. The heat transfer fluid is taken through a power cycle (such as a Kalina cycle) to generate electricity. In an embodiment, nuclear reactor 268 is a 400 MW reactor and auxiliary power unit 274 generates about 30 MW of electricity.

[0094] FIG. 9 depicts a schematic elevational view of an arrangement for an in situ heat treatment process. U-shaped wellbores may be formed in the formation to define treatment areas 264A, 264B, 264C, 264D. Additional treatment areas could be formed to the sides of the shown treatment areas. Treatment areas 264A, 264B, 264C, 264D 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 276. Rail lines 278 may be formed along sides of treatment areas 264. Warehouses, administration offices and/or spent fuel storage facilities may be located near ends of rail lines 278. Facilities 280 may be formed at intervals along spurs of rail lines 278. Each facility 280 may include a nuclear reactor, compressors and/or pumps, heat exchanger units and other equipment needed for circulating hot heat transfer fluid to the wellbores. Facilities 280 may also include surface facilities for treating formation fluid produced from the formation. In some embodiments, heat transfer fluid produced in facility 280' may be reheated by the reactor in facility 280" after passing through treatment area 264A. In some embodiments, each facility 280 is used to provide hot heat transfer fluid to wells in one half of the treatment area 264 adjacent to the facility. Facilities 280 may be moved by rail to another facility site after production from a treatment area is completed.

[0095] 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 282 and /or fuel 284 to a plurality of oxidizer assemblies like oxidizer assembly 286 depicted in FIG. 10. Each oxidizer assembly 286 may include a number of oxidizers 288. Oxidizers 288 may burn a mixture of oxidizing fluid 282 and fuel 284 to produce heat that

heats the treatment area in the formation. Also, compressors 222 may be used to supply gas phase heat transfer fluid to the formation as depicted in FIG. 3. In some embodiments, pumps provide liquid phase heat transfer fluid to the treatment area.

[0096] 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.

[0097] 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.

[0098] 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.

[0099] 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

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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
5 in the elements described herein without departing from the 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.

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CLAIMS:

1. An in situ heat treatment system for producing hydrocarbons from a subsurface formation, comprising:
 - a plurality of wellbores in the formation;
 - 5 piping positioned in at least two of the wellbores;
 - a fluid circulation system coupled to the piping;
 - a heat supply configured to heat a liquid heat transfer fluid circulated by the circulation system through the piping to heat the formation to temperatures that allow for hydrocarbon production from the formation; and
 - 10 one or more electrical heaters coupled to the piping configured to initially heat the piping to a temperature above a solidification temperature of the liquid heat transfer fluid.
2. The system as claimed in claim 1, wherein the heat supply comprises a nuclear reactor.
3. The system as claimed in claim 1, wherein the heat supply comprises a gas
15 burning furnace.
4. The system as claimed in any one of claims 1-3, wherein the heat transfer fluid comprises a molten salt.
5. The system as claimed in any one of claims 1-3, wherein the heat transfer fluid comprises a molten metal.
- 20 6. The system as claimed in any one of claims 1-5, wherein the one or more electrical heaters comprise one or more heaters placed in the piping.

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7. The system as claimed in any one of claims 1-6, wherein the electrical heater comprises one or more conductors coupled to the piping, the conductors configured to apply electricity to the piping to resistively heat the piping.

8. The system as claimed in any one of claims 1-7, wherein the circulation system
5 comprises a gas lift system configured to return molten salt to the surface.

9. A method of heating a subsurface formation, comprising:

heating a liquid heat transfer fluid using heat exchange with a heat supply,
wherein the liquid heat transfer fluid is heated to a temperature sufficient to inhibit
solidification of the liquid heat transfer fluid during use, and wherein the heat transfer fluid
10 comprises one or more molten salts;

circulating the liquid heat transfer fluid through piping in the formation to heat
a portion of the formation to allow hydrocarbons to be produced from the formation; and

producing hydrocarbons from the formation.

10. The method as claimed in claim 9, wherein the heat supply comprises a nuclear
15 reactor.

11. The method as claimed in any one of claims 9-10, further comprising returning
the liquid heat transfer fluid to the surface using a gas lift system.

12. The method as claimed in any one of claims 9-11, further comprising heating
the piping to a temperature sufficient to inhibit solidification of the molten salt in the piping
20 using one or more electrical heaters.

13. The method as claimed in claim 12, wherein heating the piping using one or
more electrical heaters comprises flowing current through the piping to resistively heat the
piping.

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14. The method as claimed in claim 12, wherein heating the piping using one more electrical heaters comprises placing a insulated conductor heater in or more portions of the piping and heating the insulated conductor heater to heat the piping.

15. A method of heating a subsurface formation, comprising:

5 passing a liquid heat transfer fluid from a vessel to a heat exchanger;

heating the liquid heat transfer fluid to a first temperature, wherein the first temperature is sufficient to inhibit solidification of the liquid heat transfer fluid, and wherein the heat transfer fluid comprises one or more molten salts;

10 flowing the liquid heat transfer fluid through a heater section to a sump, wherein heat transfers from the heater section to a treatment area in the formation; and gas lifting the liquid heat transfer fluid to the surface from the sump; and returning at least a portion of the liquid heat transfer fluid to the vessel.

16. The method as claimed in claim 15, wherein a fluid used to gas lift the liquid heat transfer fluid comprises carbon dioxide.

15 17. The method as claimed in any one of claims 15-16, wherein a fluid used to gas lift the liquid heat transfer fluid comprises methane.

18. The method as claimed in any one of claims 15-17, wherein the liquid heat transfer fluid is gas lifted from the sump through a conduit, and further comprising heating the conduit to inhibit solidification of liquid heat transfer fluid in the conduit.

20 19. The method as claimed in any one of claims 15-18, wherein the heat exchanger comprises one or more gas burners.

20. The method as claimed in any one of claims 15-19, wherein the heat exchanger comprises a tube-in-shell heat exchanger configured to transfer heat from a hot stream produced by a nuclear reactor.

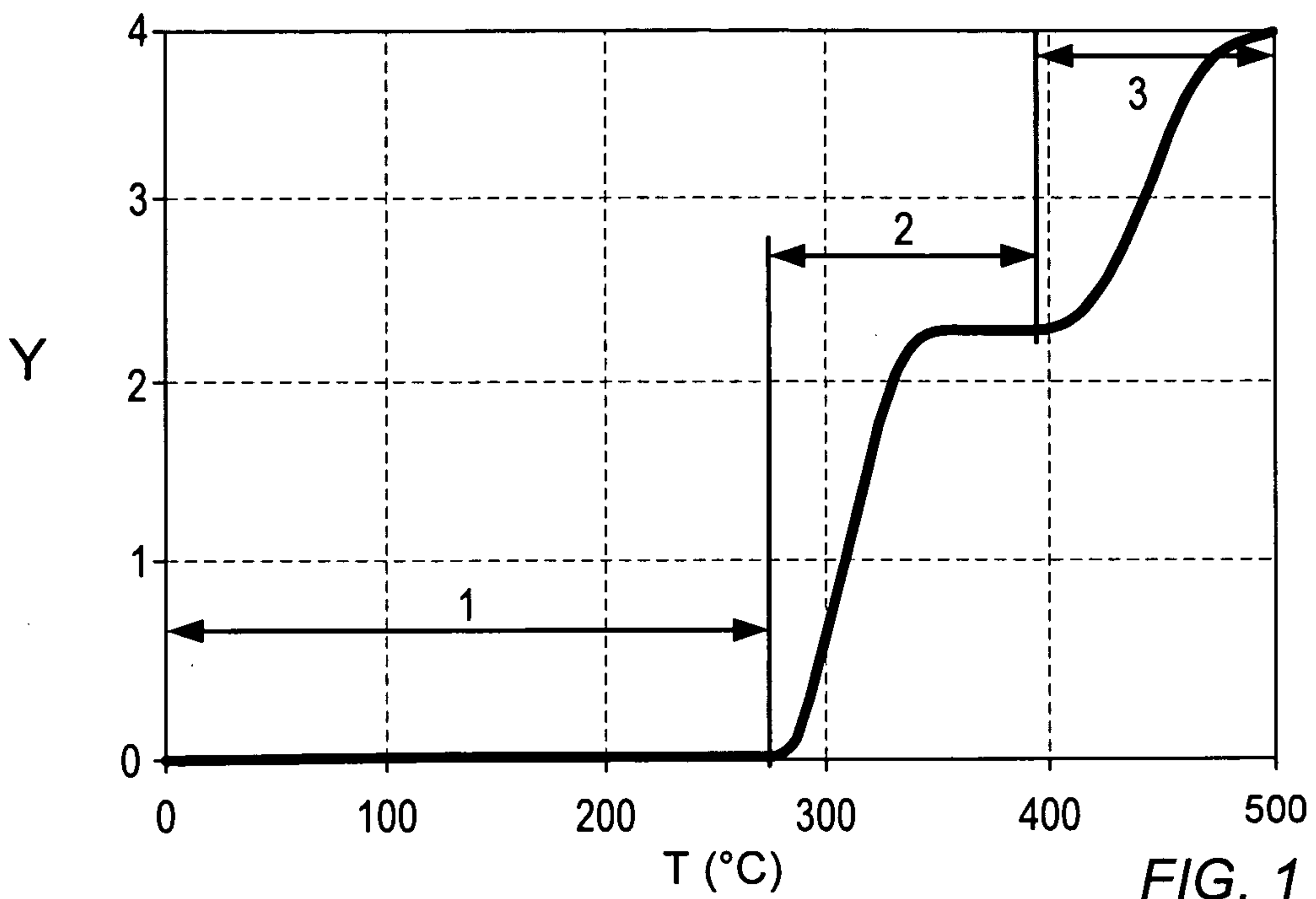


FIG. 1

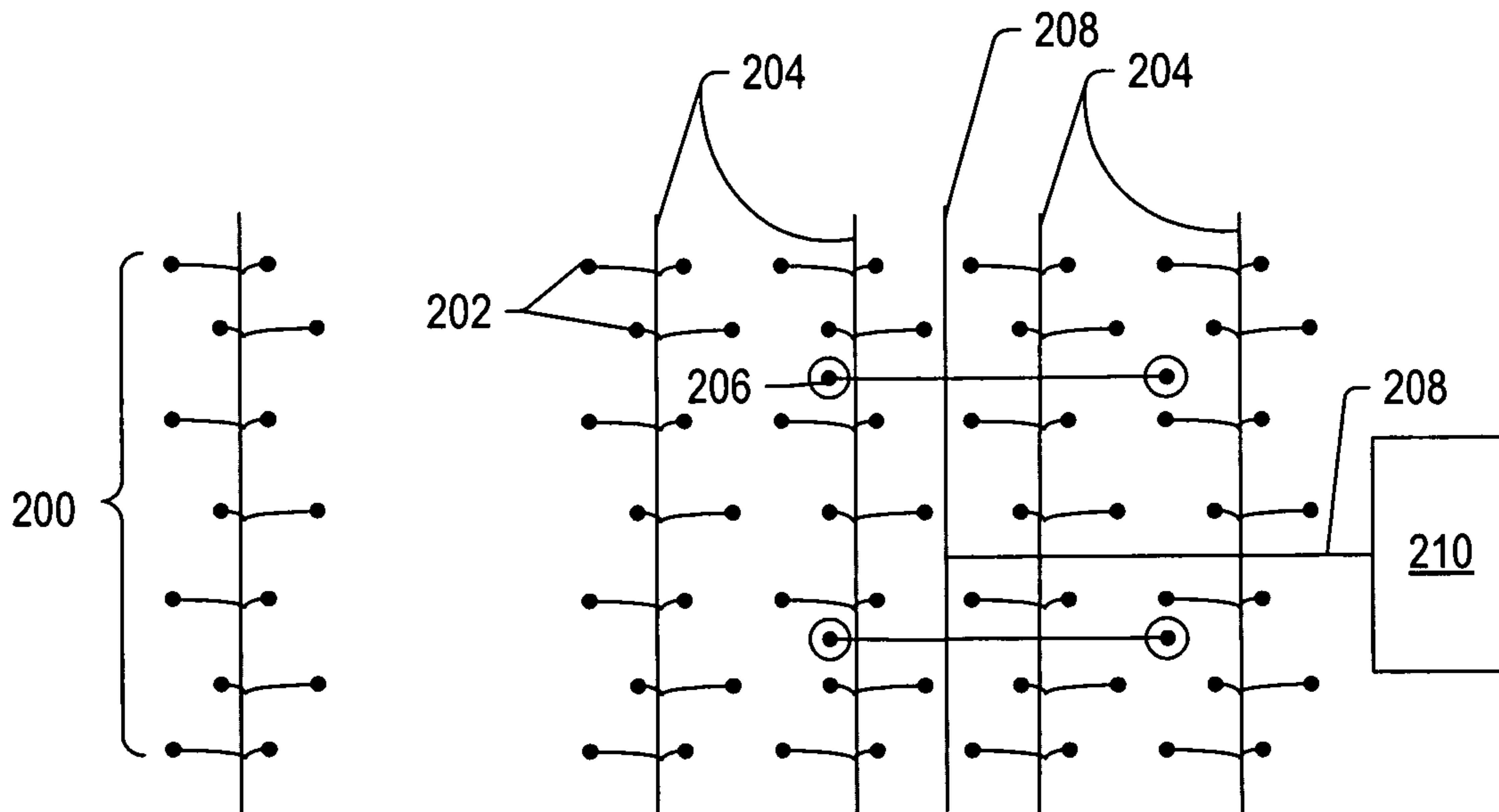


FIG. 2

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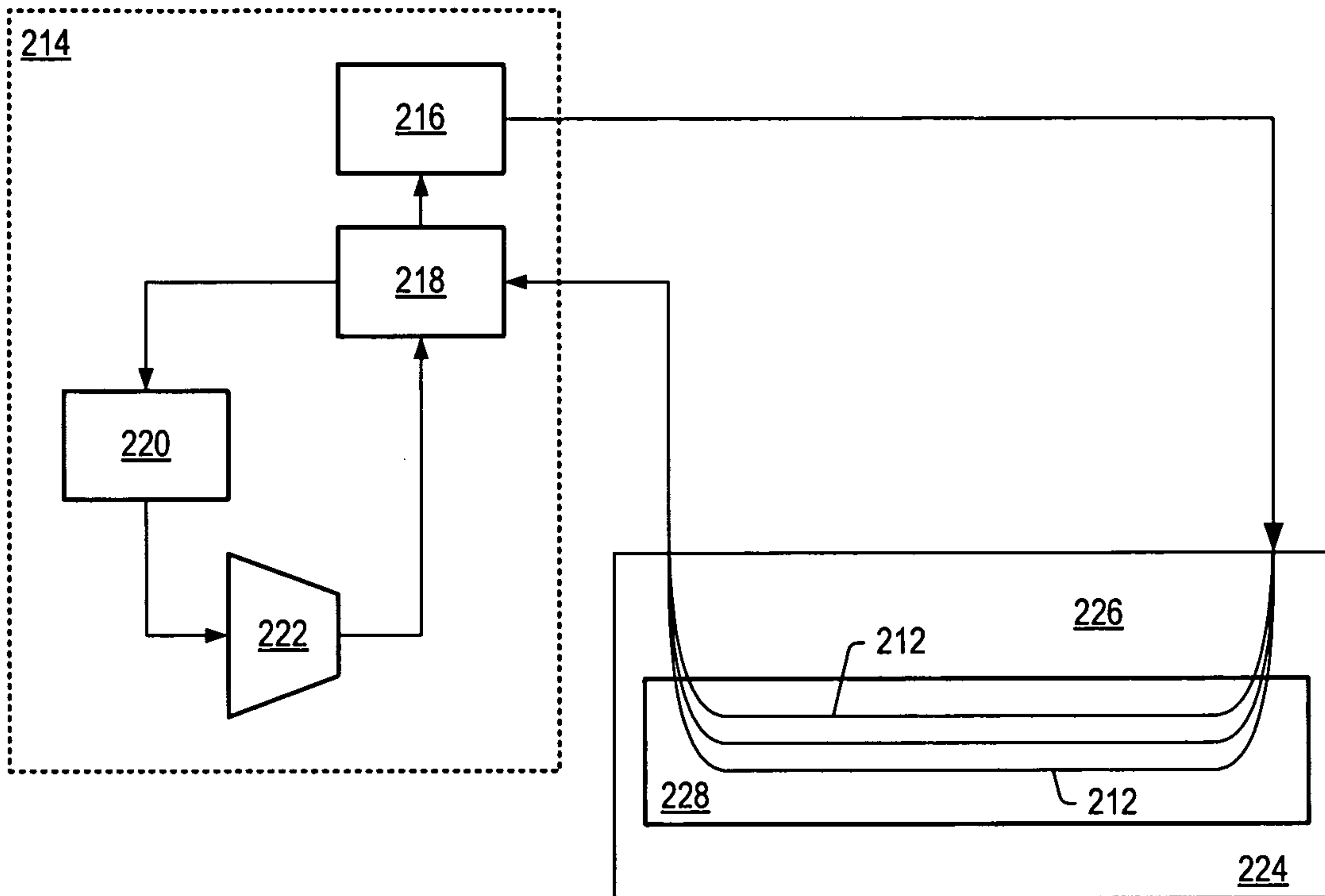


FIG. 3

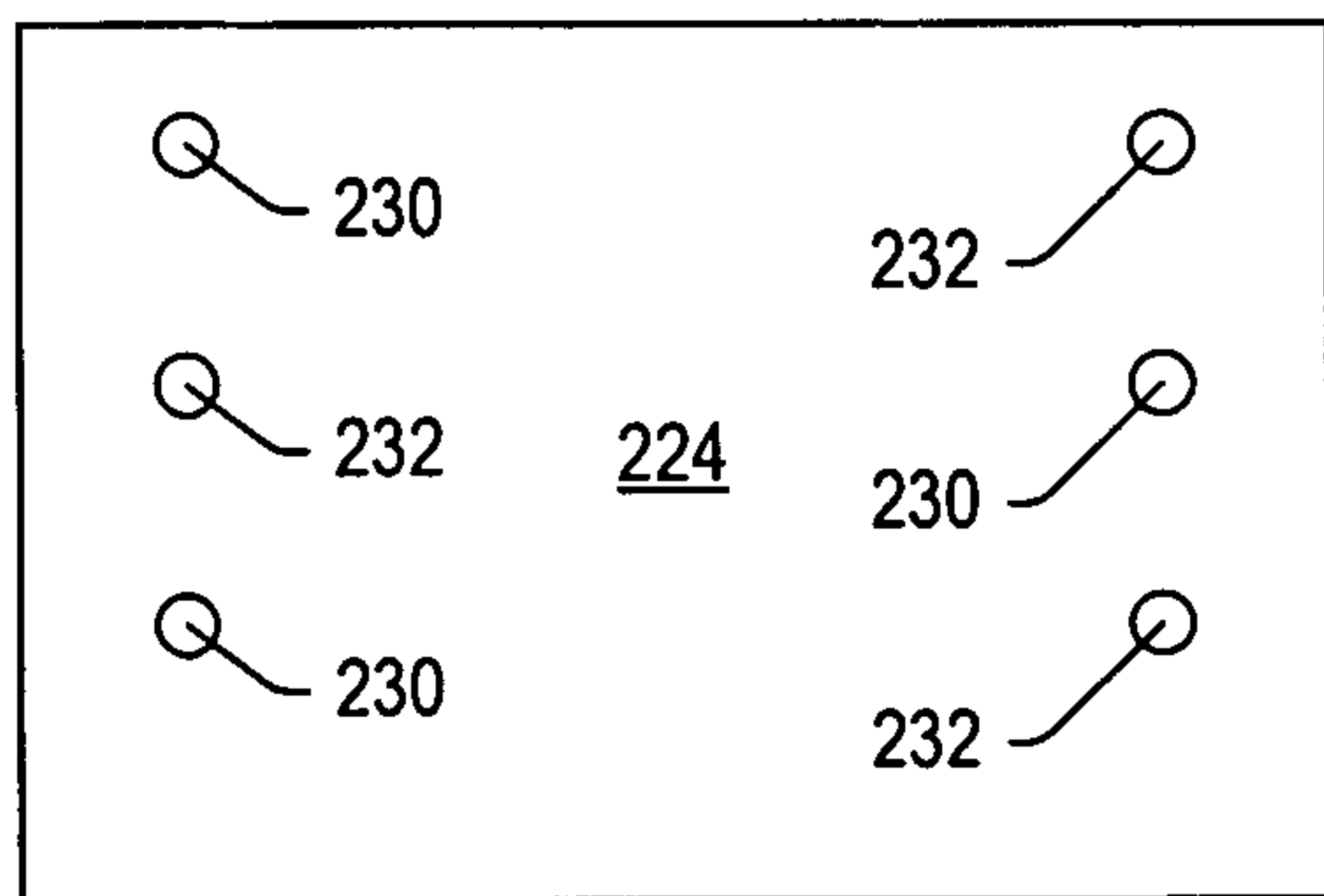


FIG. 4

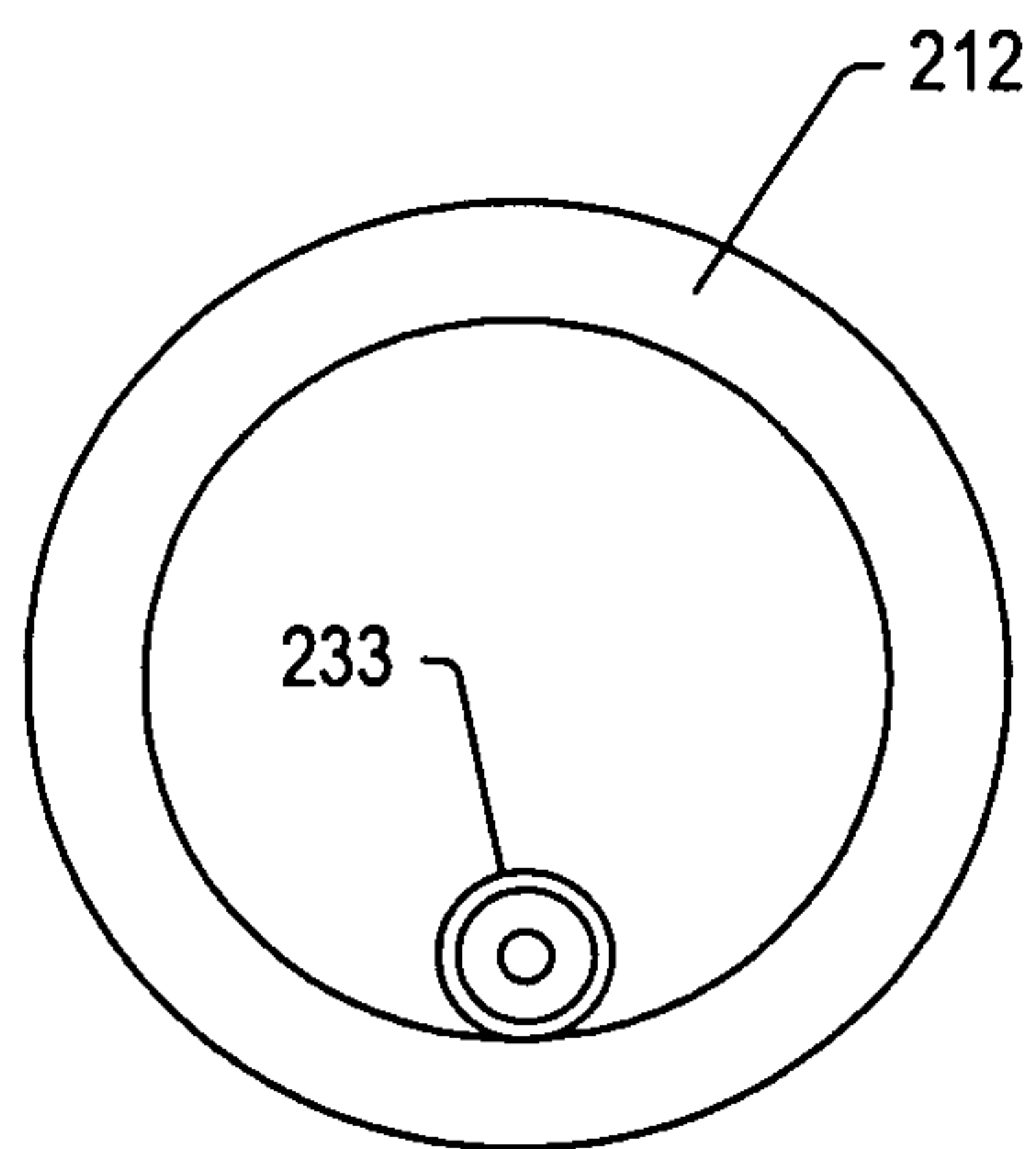


FIG. 5

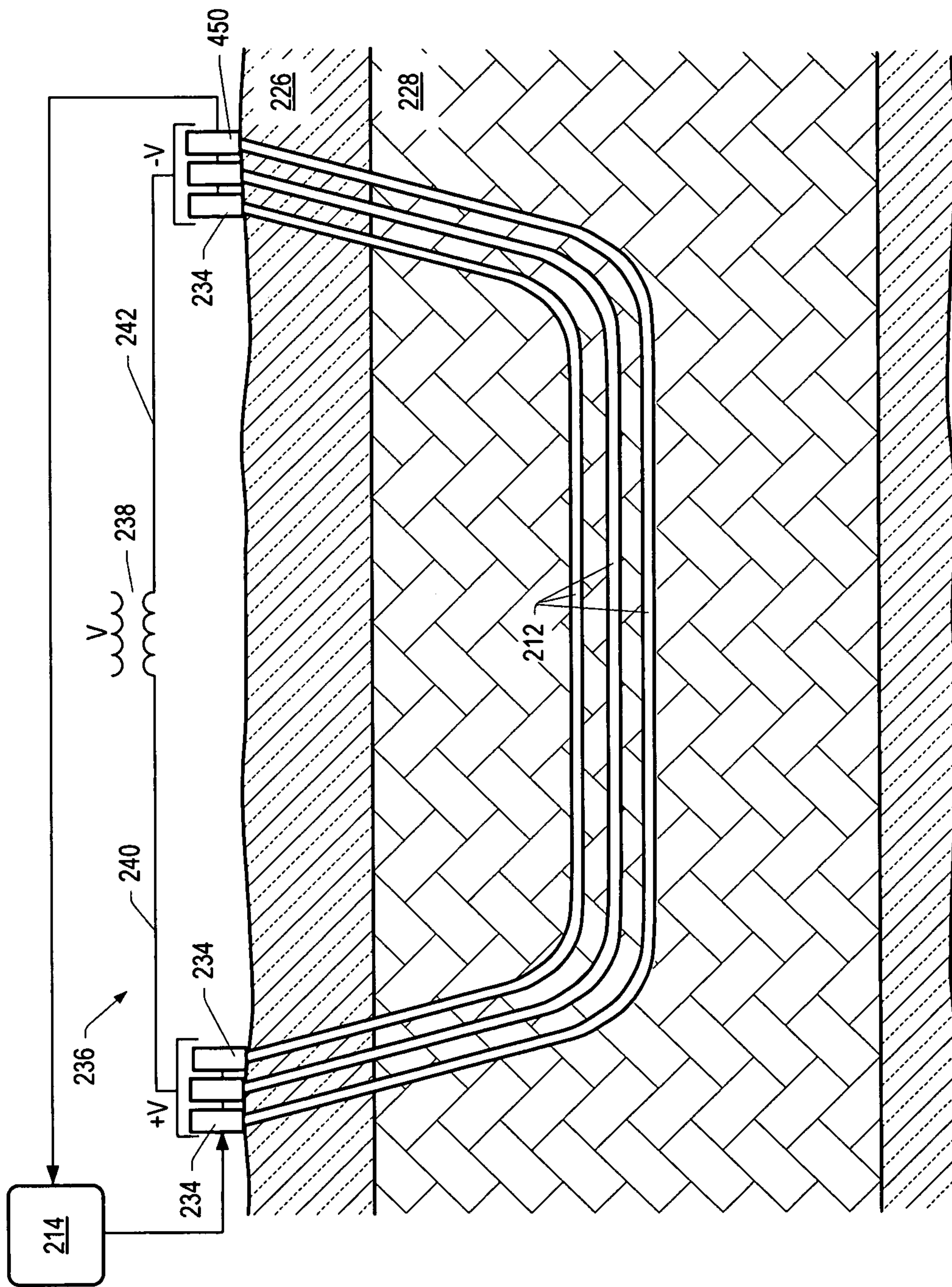


FIG. 6

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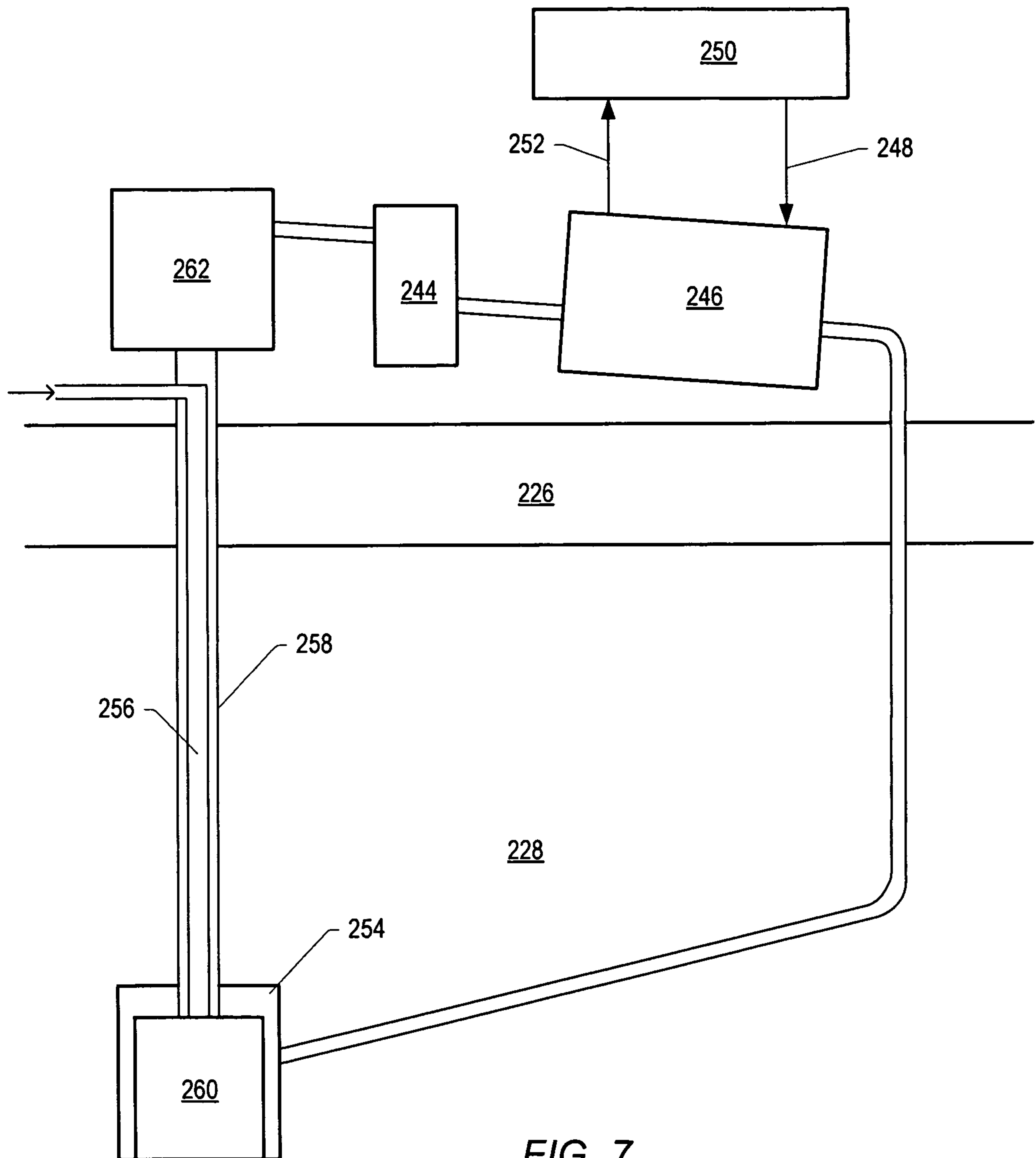


FIG. 7

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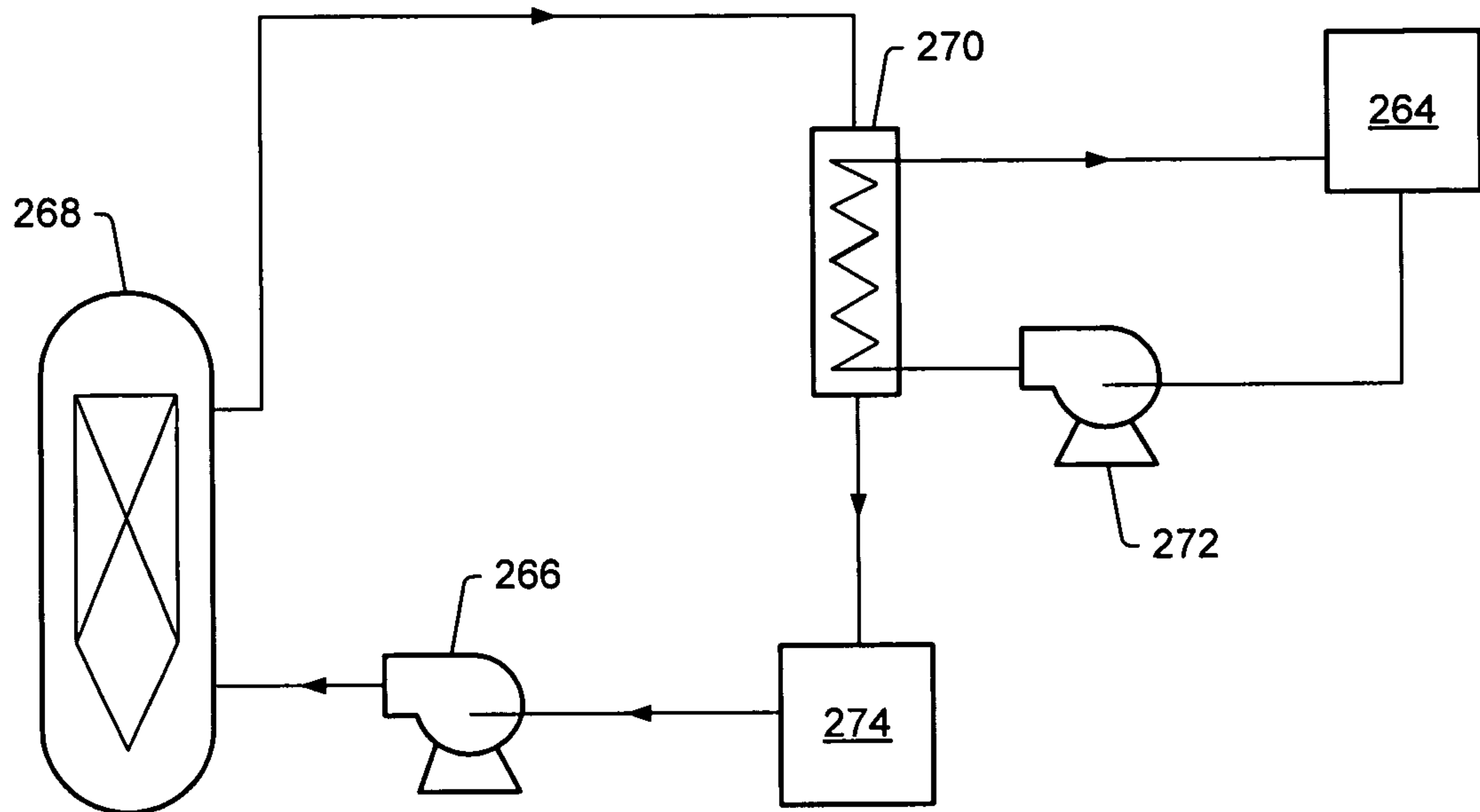


FIG. 8

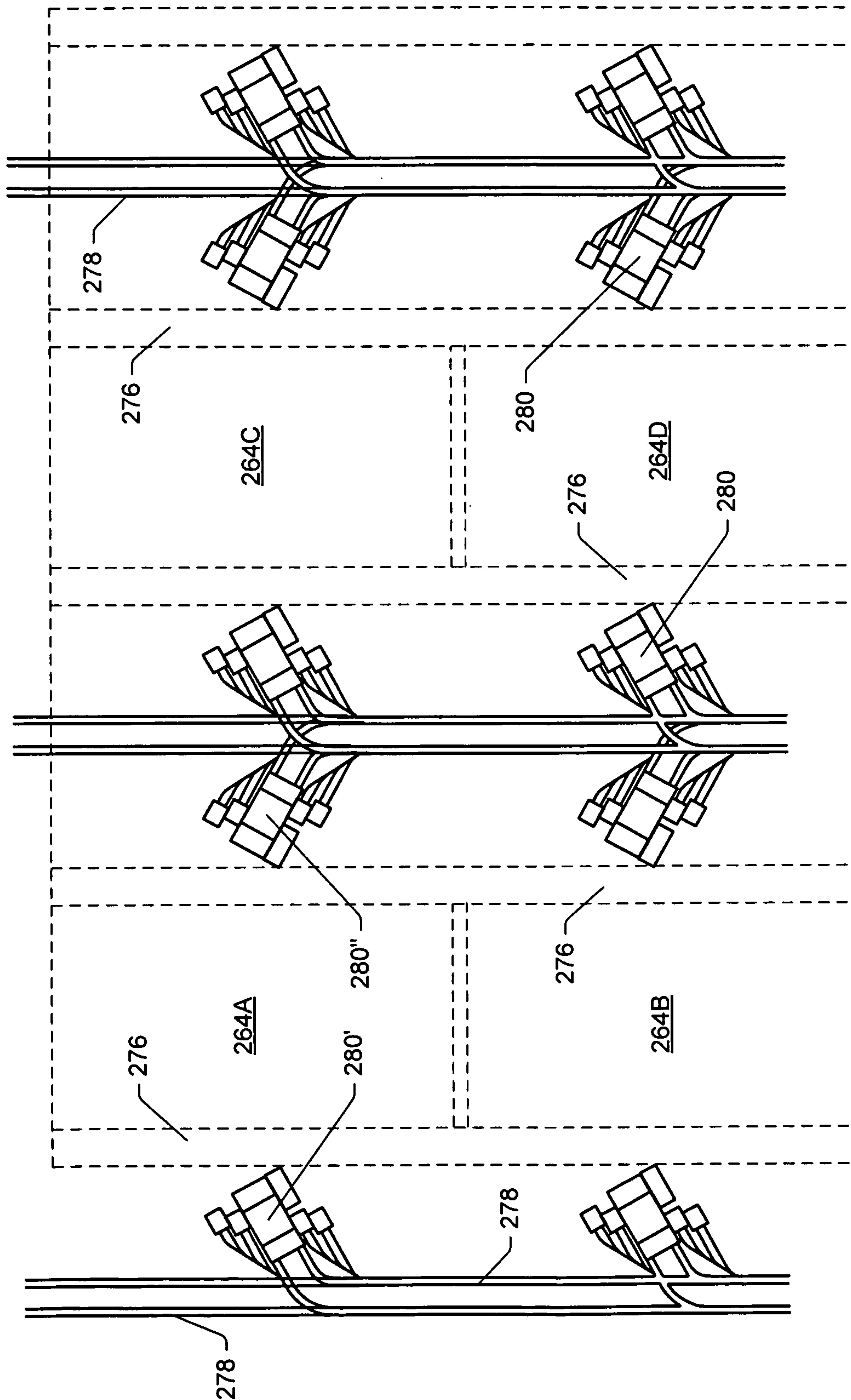


FIG. 9

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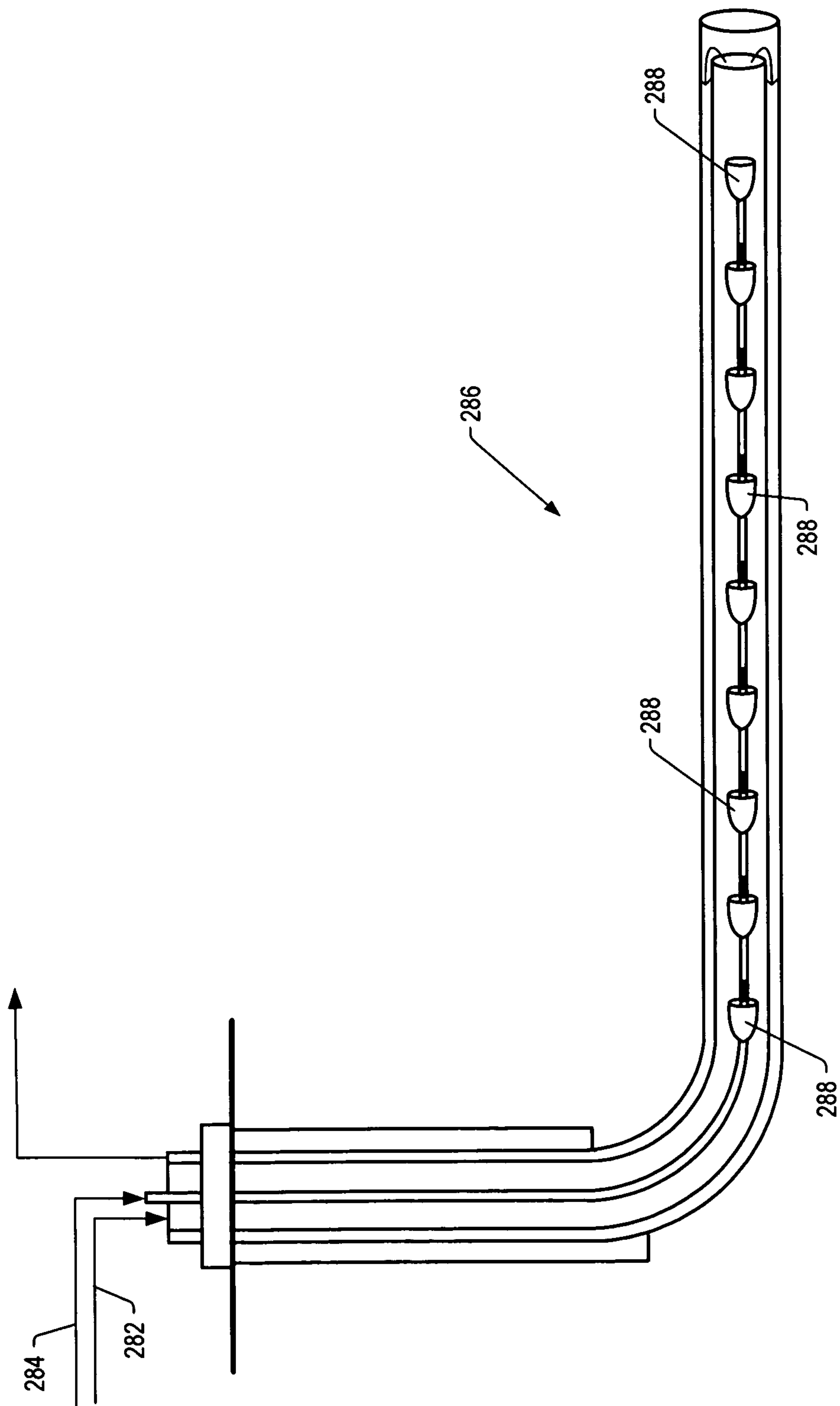


FIG. 10

