Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2684422 A1 2008/10/30

(21) 2 684 422

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2008/04/18
(87) Date publication PCT/PCT Publication Date: 2008/10/30
(85) Entrée phase nationale/National Entry: 2009/10/16
(86) N° demande PCT/PCT Application No.: US 2008/060746
(87) N° publication PCT/PCT Publication No.: 2008/131173
(30) Priorités/Priorities: 2007/04/20 (US60/925,685); 2007/10/19 (US60/999,839)

(51) Cl.Int./Int.Cl. *E21B 36/02* (2006.01)

(71) Demandeur/Applicant:
SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V., NL

(72) Inventeurs/Inventors:
NGUYEN, SCOTT VINH, US;
VINEGAR, HAROLD J., US

(74) Agent: OGILVY RENAULT LLP/S.E.N.C.R.L.,S.R.L.

(54) Titre : SYSTEMES DE CHAUFFAGE POUR CHAUFFER DES FORMATIONS DE SUB-SURFACE
(54) Title: HEATING SYSTEMS FOR HEATING SUBSURFACE FORMATIONS

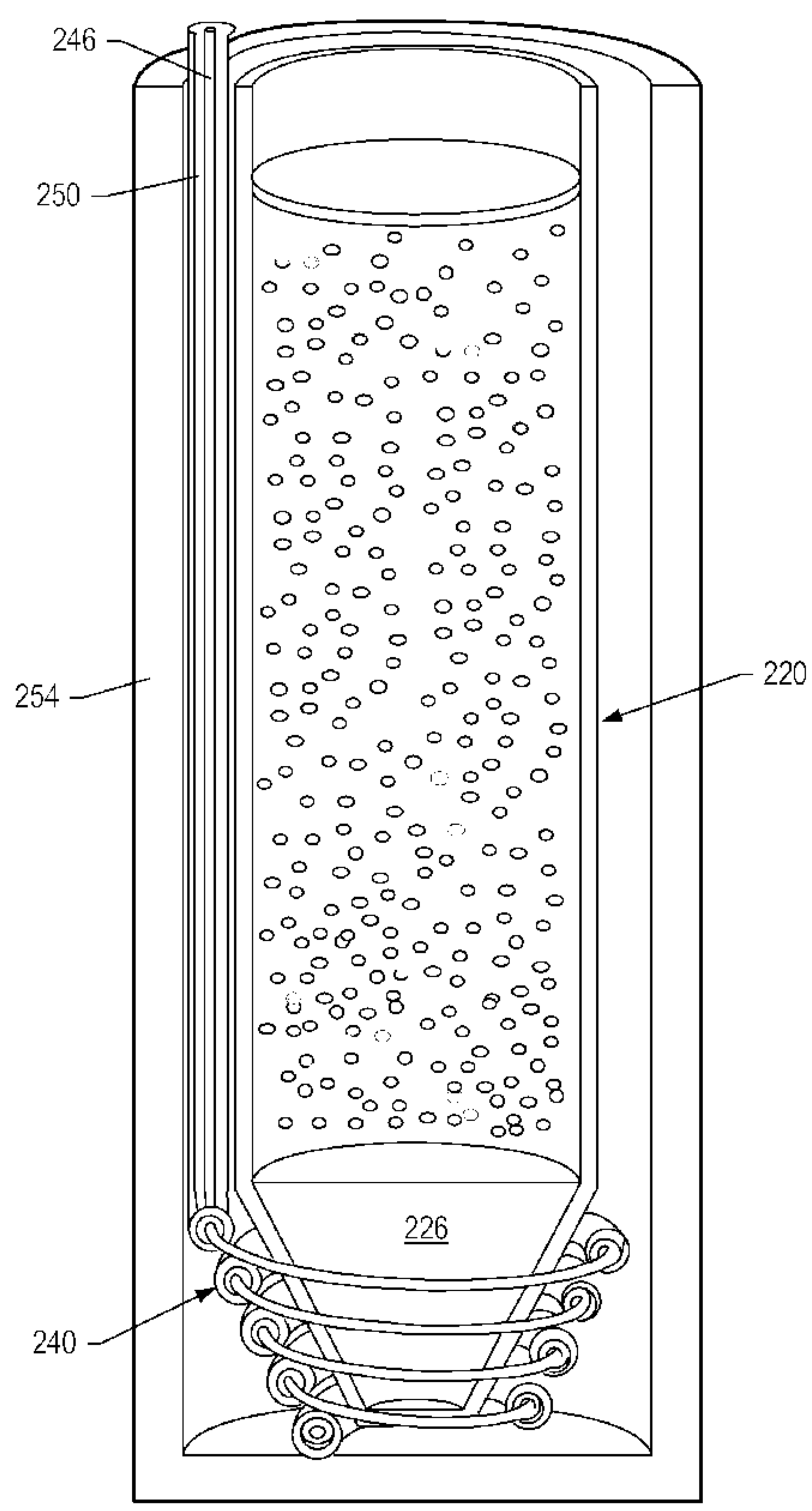

FIG. 9

(57) Abrégé/Abstract:
Methods and systems for heating a subsurface formation are described herein. A heating system for a subsurface formation includes a sealed conduit positioned in an opening in the formation and a heat source. The sealed conduit includes a heat transfer

(57) Abrégé(suite)/Abstract(continued):

fluid. The heat source provides heat to a portion of the sealed conduit to change phase of the heat transfer fluid from a liquid to a vapor. The vapor in the sealed conduit rises in the sealed conduit, condenses to transfer heat to the formation and returns to the conduit portion as a liquid.

CA 02684422 2009-10-16

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 October 2008 (30.10.2008)

PCT

(10) International Publication Number
WO 2008/131173 A1

(51) International Patent Classification:
E21B 36/02 (2006.01)

(21) International Application Number:
PCT/US2008/060746

(22) International Filing Date: 18 April 2008 (18.04.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/925,685 20 April 2007 (20.04.2007) US
60/999,839 19 October 2007 (19.10.2007) US

(71) Applicant (*for SM only*): **SHELL OIL COMPANY** [US/US]; One Shell Plaza, P.O. Box 2463, Houston, Texas 77252-2463 (US).

(71) Applicant (*for all designated States except US*): **SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.** [NL/NL]; Carel van Bylandtlaan 30, NL-2596 HR The Hague (NL).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **NGUYEN, Scott Vinh** [US/US]; 3000 Bissonnet Street, #7311, Houston, Texas 77005 (US). **VINEGAR, Harold J.** [US/US]; 4613 Laurel, Bellaire, Texas 77401 (US).

(74) Agent: **CHRISTENSEN, Del S.**; Shell Oil Company, One Shell Plaza, P.O. Box 2463, Houston, Texas 77252-2463 (US).

(81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,

[Continued on next page]

(54) Title: HEATING SYSTEMS FOR HEATING SUBSURFACE FORMATIONS

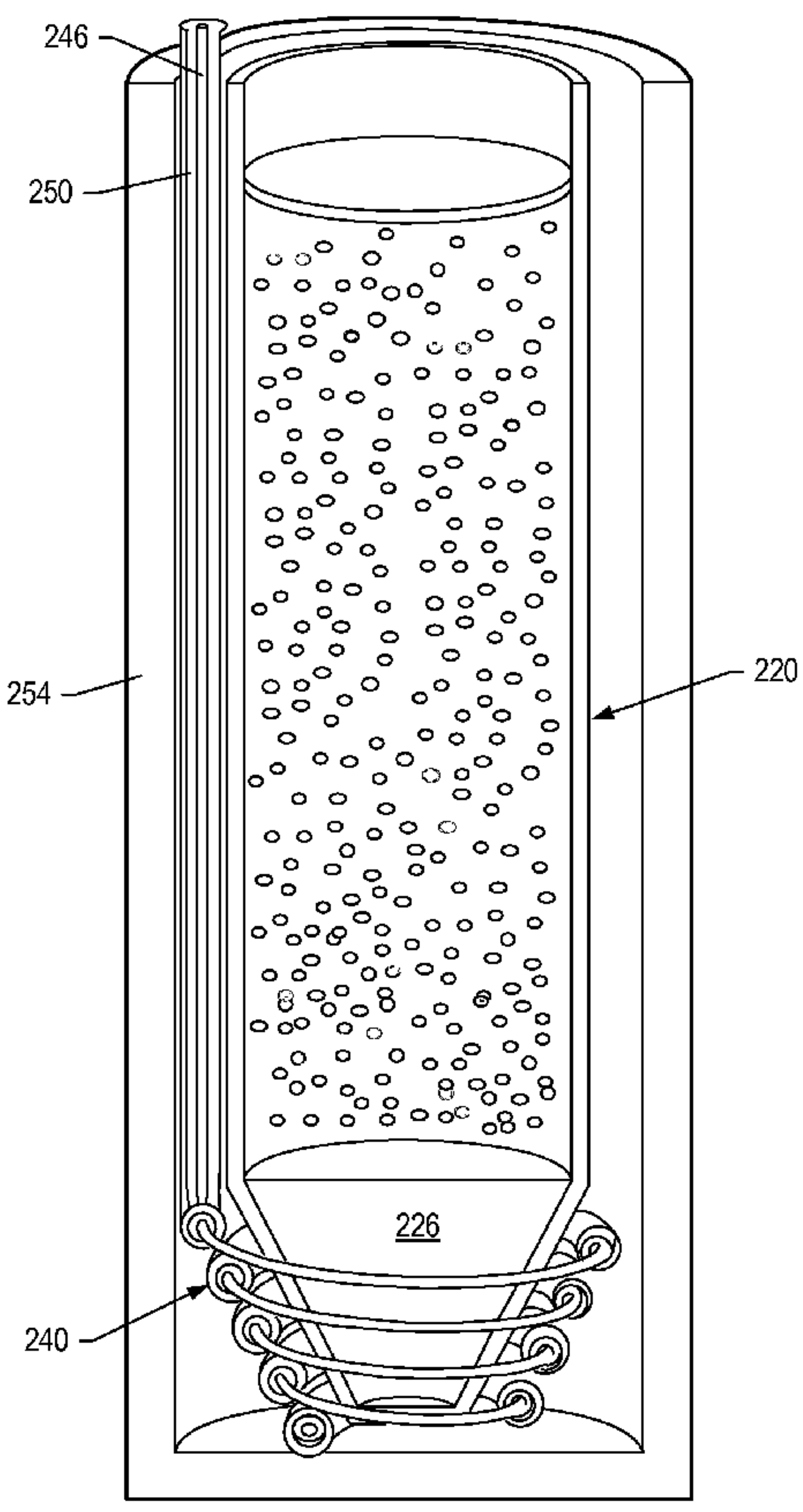

FIG. 9

(57) Abstract: Methods and systems for heating a subsurface formation are described herein. A heating system for a subsurface formation includes a sealed conduit positioned in an opening in the formation and a heat source. The sealed conduit includes a heat transfer fluid. The heat source provides heat to a portion of the sealed conduit to change phase of the heat transfer fluid from a liquid to a vapor. The vapor in the sealed conduit rises in the sealed conduit, condenses to transfer heat to the formation and returns to the conduit portion as a liquid.

WO 2008/131173 A1

WO 2008/131173 A1

ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*

HEATING SYSTEMS FOR HEATING SUBSURFACE FORMATIONS

BACKGROUND

1. Field of the Invention

[0001] The present invention relates generally to heating methods and heating 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. 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. 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 characteristics similar to liquid flow.

[0003] A wellbore may be formed in a formation. In some embodiments, a casing or other pipe system may be placed or formed in a wellbore. In some embodiments, an expandable tubular may be used in a wellbore. Heaters may be placed in wellbores to heat a formation during an in situ process.

[0004] Application of heat to oil shale formations is described in U.S. Patent Nos. 2,923,535 to Ljungstrom and 4,886,118 to Van Meurs et al. Heat may be applied to the oil shale formation to pyrolyze kerogen in the oil shale formation. The heat may also fracture the formation to increase permeability of the formation. The increased permeability may allow formation fluid to travel to a production well where the fluid is removed from the oil shale formation. In some processes disclosed by Ljungstrom, for example, an oxygen containing gaseous medium is introduced to a permeable stratum, preferably while still hot from a preheating step, to initiate combustion.

[0005] A heat source may be used to heat a subterranean formation. Electric heaters may be used to heat the subterranean formation by radiation and/or conduction. An electric heater may resistively heat an element. U.S. Patent Nos. 2,548,360 to Germain; 4,716,960 to Eastlund et al.; 4,716,960 to Eastlund et al.; and 5,065,818 to Van Egmond describes an electric heating element placed in a wellbore. U.S. Patent No. 6,023,554 to Vinegar et al. describes an electric heating element that is positioned in a casing. The heating element generates radiant energy that heats the casing.

[0006] U.S. Patent No. 4,570,715 to Van Meurs et al. describes an electric heating element. The heating element has an electrically conductive core, a surrounding layer of insulating material, and a surrounding metallic sheath. The conductive core may have a relatively low resistance at high temperatures. The insulating material may have electrical resistance, compressive strength, and heat conductivity properties that are relatively high at high temperatures. The insulating layer may inhibit arcing from the core to the metallic sheath. The metallic sheath may have tensile strength and creep resistance properties that are relatively high at high temperatures. U.S. Patent No. 5,060,287 to Van Egmond describes an electrical heating element having a copper-nickel alloy core.

[0007] Heaters may be manufactured from wrought stainless steels. U.S. Patent No. 7,153,373 to Maziasz et al. and U.S. Patent Application Publication No. US 2004/0191109 to Maziasz et al. described modified 237 stainless steels as cast microstructures or fined grained sheets and foils.

[0008] As outlined above, there has been a significant amount of effort to develop heaters, 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 still a need for improved heating methods and systems for production of hydrocarbons, hydrogen, and/or other products from various hydrocarbon containing formations.

SUMMARY

[0009] Embodiments described herein generally relate to systems, methods, and heaters for treating a subsurface formation.

[0010] The invention advantageously provides a heating system for a subsurface formation comprising: a sealed conduit positioned in an opening in the formation, wherein a heat transfer fluid is positioned in the conduit; a heat source configured to provide heat to a portion of the sealed conduit to change phase of the heat transfer fluid from a liquid to a vapor; and wherein the vapor in the sealed conduit rises in the sealed conduit, condenses to transfer heat to the formation and returns to the portion as a liquid.

[0011] The invention advantageously provides a heating system for heating a subsurface formation comprising: a plurality of heaters positioned in the formation, the plurality of heaters configured to heat a portion of the formation; and a plurality of heat pipes positioned in the heated portion, wherein at least one of the heat pipes comprises a liquid heating portion, wherein heat from one or more of the plurality of heaters is configured to provide heat to the liquid heating portion sufficient to vaporize at least a portion of a liquid in the heat pipe, wherein the vapor rises in the heat pipe, condenses in the heat pipe and transfers heat to the formation, and wherein condensed fluid flows back to the liquid heating portion.

[0012] In addition to the above advantages the invention provides heaters and/or heat sources comprising one or more downhole gas burners and/or electric heaters.

[0013] In addition to the above advantages the invention provides that at least a portion of exhaust gases from one or more of the downhole gas burners passes between the heat pipe and an outer conduit to the surface.

[0014] In addition to the above advantages the invention provides at least one heat pipe is oriented substantially vertically in the formation.

[0015] In addition to the above advantages the invention provides wherein at least one heat pipe is oriented substantially horizontally in the formation with the heat pipe angled upwards relative to horizontal.

[0016] In addition to the above advantages the invention provides at least one heat pipe is oriented substantially horizontally in the formation with the heat pipe angled downwards relative to horizontal.

[0017] In addition to the above advantages the invention provides wherein the liquid in one more heat pipes or the heat transfer fluid comprises molten metal and/or a molten metal salt.

[0018] The invention advantageously provides a method for heating a subsurface formation, comprising: heating portions of sealed conduits positioned in the formation using heat sources, wherein the heat sources vaporize heat transfer fluid in the sealed conduits, wherein the vapor rises in the sealed conduits, condenses to transfer heat to the sealed conduits, and flows back to the heated portions of the sealed conduits; and allowing heat from the sealed conduits to transfer to the formation to heat a portion of the formation.

[0019] 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.

[0020] In further embodiments, treating a subsurface formation is performed using any of the methods, systems, or heaters described herein.

[0021] In further embodiments, additional features may be added to the specific embodiments described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Further 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:

[0023] FIG. 1 depicts an illustration of stages of heating a hydrocarbon containing formation.

[0024] FIG. 2 shows a schematic view of an embodiment of a portion of an in situ heat treatment system for treating a hydrocarbon containing formation.

[0025] FIG. 3 depicts a schematic cross-sectional representation of a portion of a formation with heat pipes positioned adjacent to a substantially horizontal portion of a heat source.

[0026] FIG. 4 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with the heat pipe located radially around an oxidizer assembly.

[0027] FIG. 5 depicts a cross-sectional representation of an angled heat pipe embodiment with an oxidizer assembly located near a lowermost portion of the heat pipe.

[0028] FIG. 6 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.

[0029] FIG. 7 depicts a cross-sectional representation of an angled heat pipe embodiment with an oxidizer located at the bottom of the heat pipe.

[0030] FIG. 8 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.

[0031] FIG. 9 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with a tapered bottom that accommodates multiple oxidizers.

[0032] FIG. 10 depicts a cross-sectional representation of a heat pipe embodiment that is angled within the formation.

DETAILED DESCRIPTION

[0033] 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. An improved heating system and method for heating a subsurface formation is described herein.

[0034] "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.

[0035] 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.

[0036] "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.

[0037] 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.

[0038] 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.

[0039] "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.

[0040] 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.

[0041] 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.

[0042] "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.

[0043] "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.

[0044] "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.

[0045] "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.

[0046] "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.

[0047] "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).

[0048] "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.

[0049] "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.

[0050] 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".

[0051] 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."

[0052] 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).

[0053] 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. For example, 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.

[0054] 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.

[0055] 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. 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.

[0056] In some in situ heat treatment embodiments, a portion of the formation is heated to a desired temperature instead of slowly heating 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.

[0057] 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 an 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.

[0058] 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.

[0059] 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.

[0060] 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. As shown 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.

[0061] 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.

[0062] 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.

[0063] 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 (C6 and above) in the production well, and/or (5) increase formation permeability at or proximate the production well.

[0064] 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 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.

[0065] In some hydrocarbon containing formations, production of hydrocarbons from the formation is inhibited until at least some hydrocarbons in the formation have been 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 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.

[0066] 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-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.

[0067] 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 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 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.

[0068] 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.

[0069] 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.

[0070] 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.

[0071] 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 (e.g., generally below about 900 °C), a low viscosity at temperatures below above 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 $SrCl_2$.

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
ThI_4	566	837
SnF_2	215	850
SnI_2	320	714
$ZnCl_2$	290	732

[0072] FIG. 3 depicts schematic cross-sectional representation of a portion of the formation with heat pipes 220 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 220 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 220 mechanically attach to heat source 202. Heat pipes 220 may be spaced a desired distance apart. In some embodiments, heat pipes 220 are spaced apart by about 12.2 meters. In other embodiments, large or smaller spacings are used. Heat pipes 220 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 220 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 220 may be vertically positioned in the formation. In some embodiments, heat pipes 220 are placed at an angle in the formation.

[0073] Heat pipes 220 may include sealed conduit 222, seal 224, liquid heat transfer fluid 226 and vaporized heat transfer fluid 228. In some embodiments, heat pipes 220 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 222 may have first portion 230 and second portion 232. Liquid heat transfer fluid 226 may be in first portion 230. Heat source 202, external to heat pipe 220, supplies sufficient heat to vaporize liquid heat transfer fluid 226. Vaporized heat transfer fluid 228 diffuses into second portion 232. Vaporized heat transfer fluid 228 condenses in second portion and transfers heat to conduit 222, which in turn transfers heat to the formation. The condensed liquid heat transfer fluid 226 flows by gravity and/or by capillary forces to first portion 230.

[0074] Position of seal 224 is a factor in determining the effective length of heat pipe 220. The effective length of heat pipe 220 may also depend on the physical properties of the heat transfer fluid and the cross-sectional area of conduit 222. Enough heat transfer fluid may be placed in conduit 222 so that some liquid heat transfer fluid 226 is present in first portion 230 at all times.

[0075] Seal 224 may provide a top seal for conduit 222. In some embodiments, conduit 222 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 222 to evacuate the conduit before the conduit is sealed. Drawing a vacuum on conduit 222 before sealing the conduit may enhance vapor diffusion throughout the conduit. In some embodiments, an oxygen getter may be introduced in conduit 222 to react with any oxygen present in the conduit.

[0076] FIG. 4 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with heat pipe 220 located radially around an oxidizer assembly. Oxidizers 242 of oxidizer assembly 240 are positioned adjacent to first portion 230 of heat pipe 220. Fuel may be supplied to oxidizers 242 through fuel conduit 246. Oxidant may be supplied to oxidizers 242 through oxidant conduit 250. Exhaust gas may flow through the space between outer conduit 254 and oxidant conduit 250. Oxidizers 242 combust fuel to provide heat that vaporizes liquid heat transfer fluid 226. Vaporized heat transfer fluid 228 rises in heat pipe 220 and condenses on walls of the heat pipe to transfer heat to sealed conduit 222. Exhaust gas from oxidizers 242 provides heat along the length of sealed conduit 222. The heat provided by the exhaust gas along the effective length of heat pipe 220 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.

[0077] FIG. 5 depicts a cross-sectional representation of an angled heat pipe embodiment with oxidizer assembly 240 located near a lowermost portion of heat pipe 220. Fuel may be supplied to oxidizers 242 through fuel conduit 246. Oxidant may be supplied to oxidizers 242 through oxidant conduit 250. Exhaust gas may flow through the annulus of heat pipe 220 and between outer conduit 254 and the heat pipe.

[0078] FIG. 6 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with oxidizer 242 located at the bottom of heat pipe 220. Fuel may be supplied to oxidizer 242 through fuel conduit 246. Oxidant may be supplied to oxidizer 242 through oxidant conduit 250. Exhaust gas may flow through the space between the outer wall of heat pipe 220 and outer conduit 254. Oxidizer 242 combusts fuel to provide heat that vaporizers liquid heat transfer fluid 226. Vaporized heat transfer fluid 228 rises in heat pipe 220 and condenses on walls of the heat pipe to transfer heat to sealed conduit 222. Exhaust gas from oxidizers 242 provides heat along the length of sealed conduit 222 and to outer conduit 254. The heat provided by the exhaust gas along the effective length of heat pipe 220 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 7 depicts a similar embodiment with heat pipe 220 positioned at an angle in the formation.

[0079] FIG. 8 depicts a perspective cut-out representation of a portion of a heat pipe embodiment with oxidizer 242 that produces flame zone adjacent to liquid heat transfer fluid 226 in the bottom of heat pipe 220. Fuel may be supplied to oxidizer 242 through fuel conduit 246. Oxidant may be supplied to oxidizer 242 through oxidant conduit 250. Oxidant and fuel are mixed and combusted to produce flame zone 256. Flame zone 256 provides heat that vaporizes liquid heat transfer fluid 226. Exhaust gases from oxidizer 242 may flow through the space between oxidant conduit 250 and the inner surface of heat pipe 220, and through the space between the outer surface of the heat pipe and outer conduit 254. The heat provided by the exhaust gas along the effective length of heat pipe 220 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.

[0080] FIG. 9 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 240 may provide high heat input to liquid heat transfer fluid 226 of heat pipe 220. A portion of oxidizer assembly with the oxidizers may be helically wound around a tapered portion of heat pipe 220. The tapered portion may have a large surface area to accommodate the oxidizers. Fuel may be supplied to the oxidizers of oxidizer assembly 240 through fuel conduit 246. Oxidant may be supplied to oxidizer 242 through oxidant conduit 250. Exhaust gas may flow through the space between the outer wall of heat pipe 220 and outer conduit 254. Exhaust gas from oxidizers 242 provides heat along the length of sealed conduit 222 and to outer conduit 254. The heat provided by the exhaust gas along the effective length of heat pipe 220 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.

[0081] FIG. 10 depicts a cross-sectional representation of a heat pipe embodiment that is angled within the formation. First wellbore 234 and second wellbore 236 are drilled in the formation using magnetic ranging or techniques so that the first wellbore intersects the second wellbore. Heat pipe 220 may be positioned in first wellbore 234. First wellbore 234 may be sloped so that liquid heat transfer fluid 226 within heat pipe 220 is positioned near the intersection of the first wellbore and second wellbore 236. Oxidizer assembly 240 may be positioned in second wellbore 236. Oxidizer assembly 240 provides heat to heat pipe that vaporizes liquid heat transfer fluid in the heat pipe. Packer or seal 238 may direct exhaust gas from oxidizer assembly 240 through first wellbore 234 to provide additional heat to the formation from the exhaust gas.

[0082] 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 heating system for a subsurface formation, comprising:

a sealed conduit positioned in an opening in the formation, wherein a heat transfer fluid is positioned in the conduit;

a heat source configured to provide heat to a portion of the sealed conduit to change phase of the heat transfer fluid from a liquid to a vapor; and

wherein the vapor in the sealed conduit rises in the sealed conduit, condenses to transfer heat to the formation and returns to the portion as a liquid.

2. The heating system of claim 1, wherein the heat source comprises a downhole gas burner and/or an electrical heater.

3. The heating system of claim 1 or 2, wherein the heat transfer fluid comprises a molten metal and/or a molten metal salt.

4. A system for heating a subsurface formation, comprising:

a plurality of heaters positioned in the formation, the plurality of heaters configured to heat a portion of the formation; and

a plurality of heat pipes positioned in the heated portion, wherein at least one of the heat pipes comprises a liquid heating portion, wherein heat from one or more of the plurality of heaters is configured to provide heat to the liquid heating portion sufficient to vaporize at least a portion of a liquid in the heat pipe, wherein the vapor rises in the heat pipe, condenses in the heat pipe and transfers heat to the formation, and wherein condensed fluid flows back to the liquid heating portion.

5. The heating system of claim 4, wherein at least one heat pipe is oriented substantially vertically in the formation.

6. The heating system of claim 4, wherein at least one heat pipe is oriented substantially horizontally in the formation with the heat pipe angled upwards relative to horizontal.

7. The heating system of claim 4, wherein at least one heat pipe is oriented substantially horizontally in the formation with the heat pipe angled downwards relative to horizontal.

8. The heating system of any of claims 4-7, wherein the plurality of heaters comprises one or more electrical heaters.

9. The heating system of claim 4-7, wherein the plurality of heaters comprises one or more downhole gas burners.

10. The heating system of claim 9, wherein at least a portion of exhaust gases from one or more of the downhole gas burners passes between the heat pipe and an outer conduit to the surface.

11. The heating system of claim 4-7, wherein the liquid in one more heat pipes comprises molten metal.

12. The heating system of claim 4-7, wherein the liquid in one or more heat pipes comprises molten metal salt.

13. A method for heating a subsurface formation, comprising:

heating portions of sealed conduits positioned in the formation using heat sources, wherein the heat sources vaporize heat transfer fluid in the sealed conduits, wherein the vapor rises in the sealed conduits, condenses to transfer heat to the sealed conduits, and flows back to the heated portions of the sealed conduits; and

allowing heat from the sealed conduits to transfer to the formation to heat a portion of the formation.

14. The method of claim 13, wherein one or more of the heat sources comprise gas burners.

15. The method of claim 13, wherein one or more of the heat sources comprise electrical heaters.

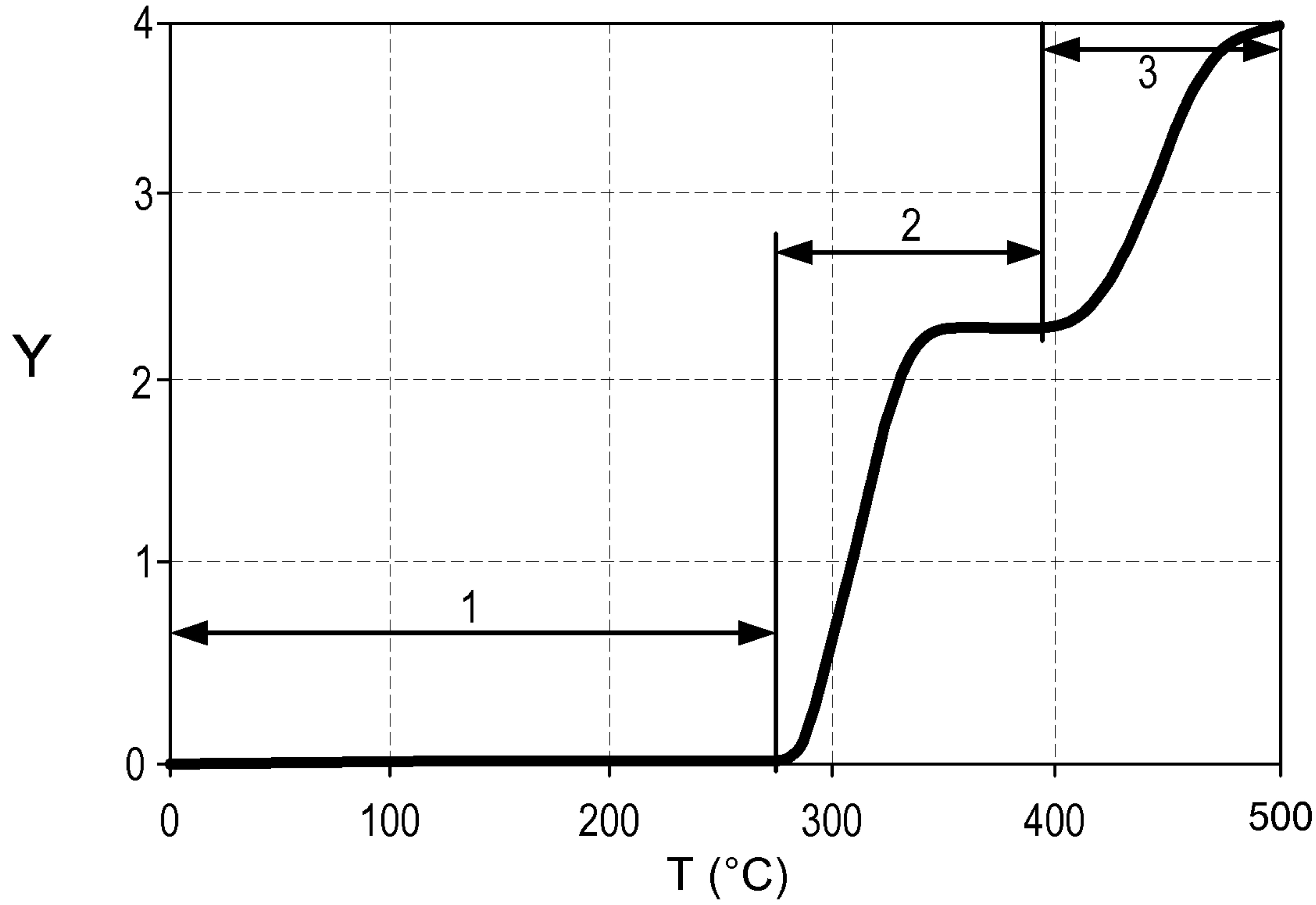
Y
4
3
2
1
0
0
100
200
300
400
500
T (°C)
1
2
3

FIG. 1

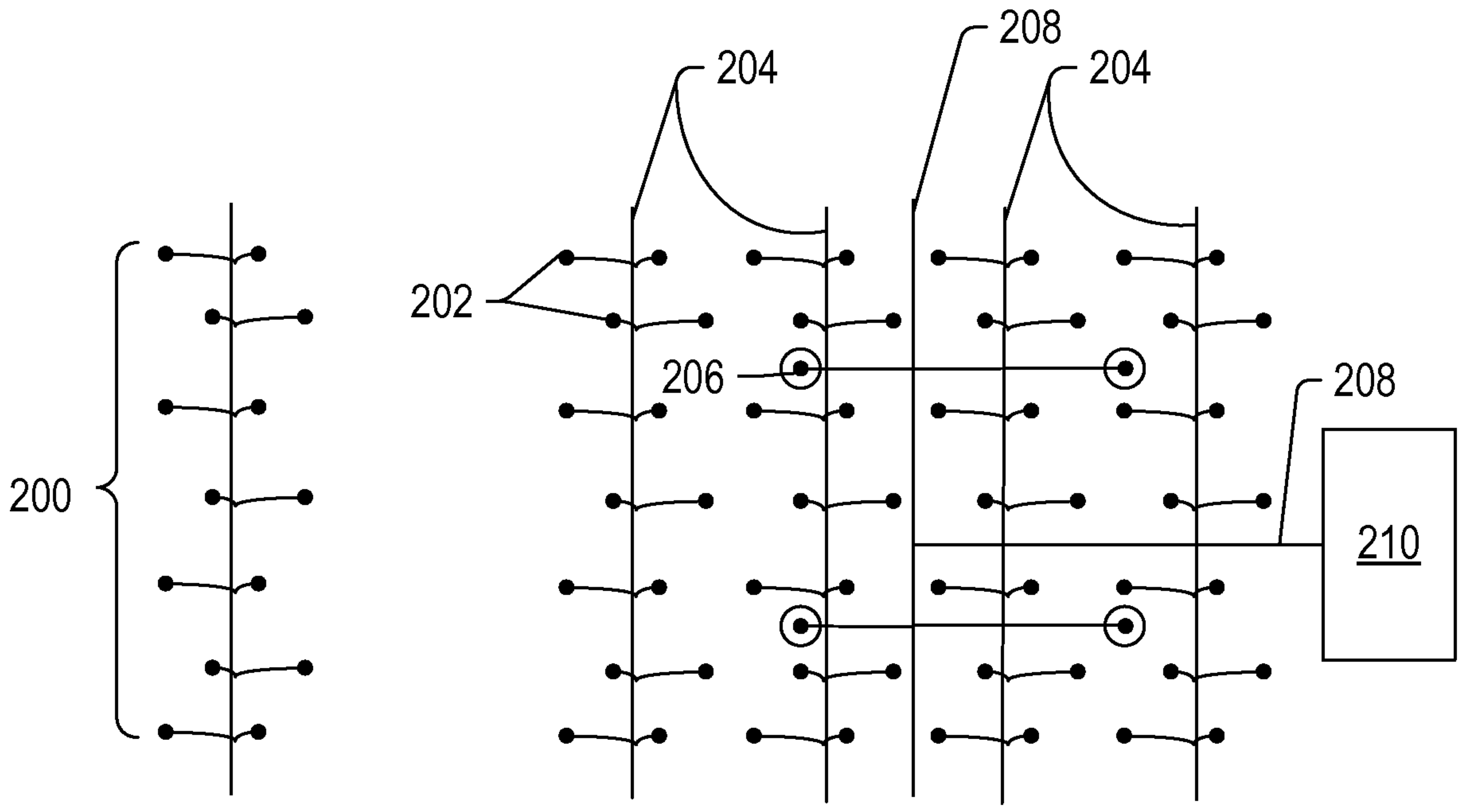
200
202
204
204
206
208
208
210

FIG. 2

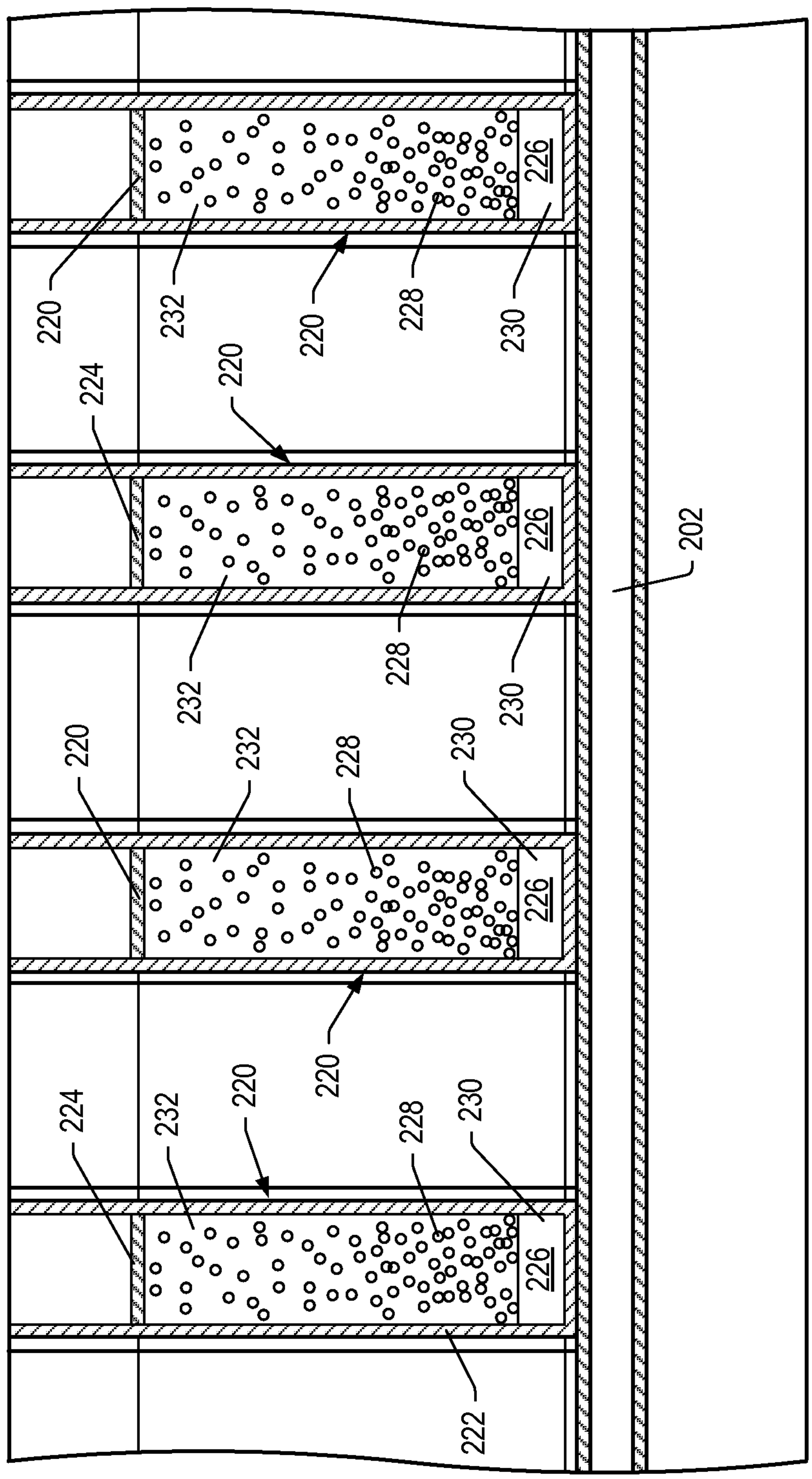

FIG. 3

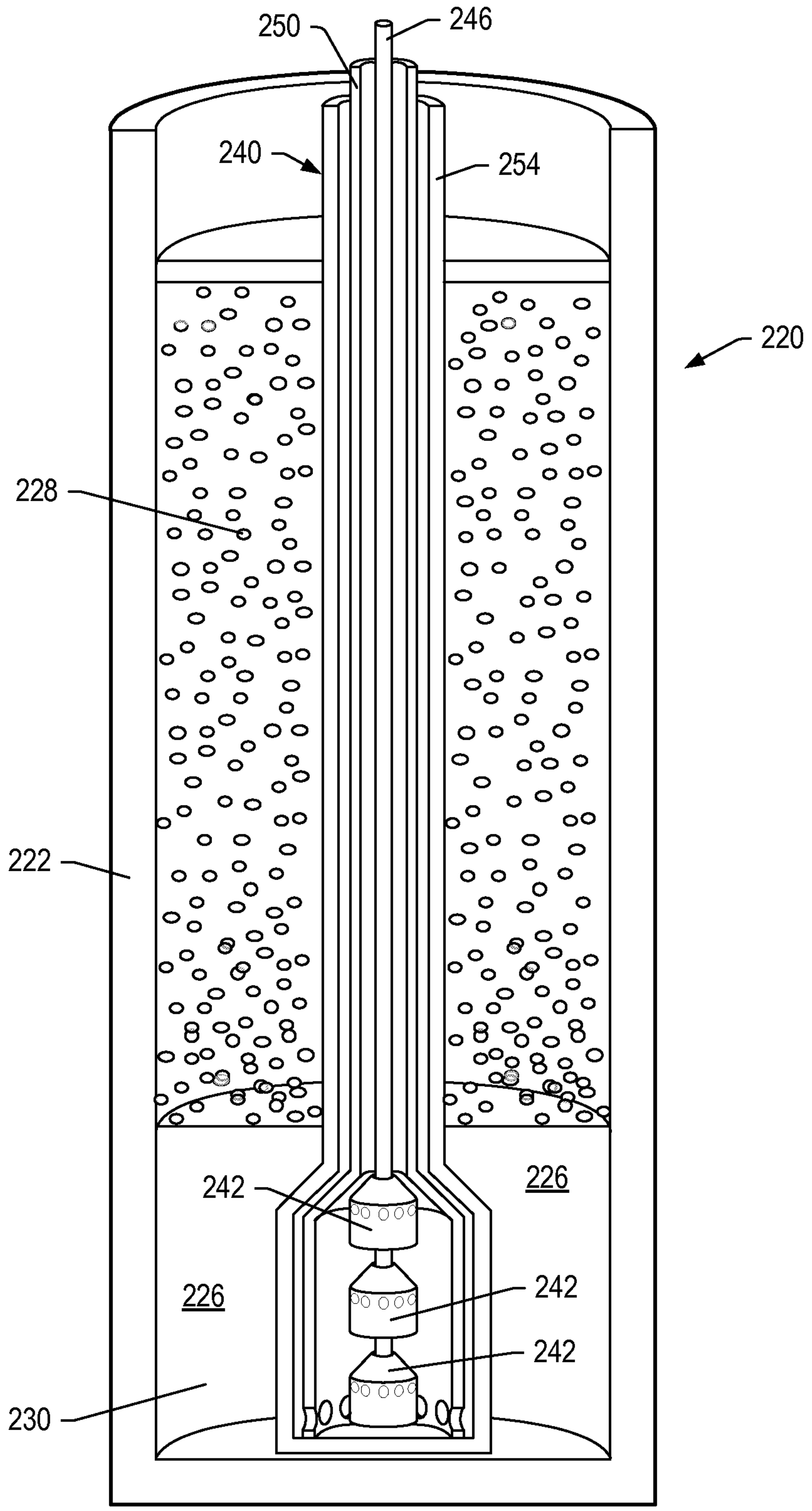

FIG. 4

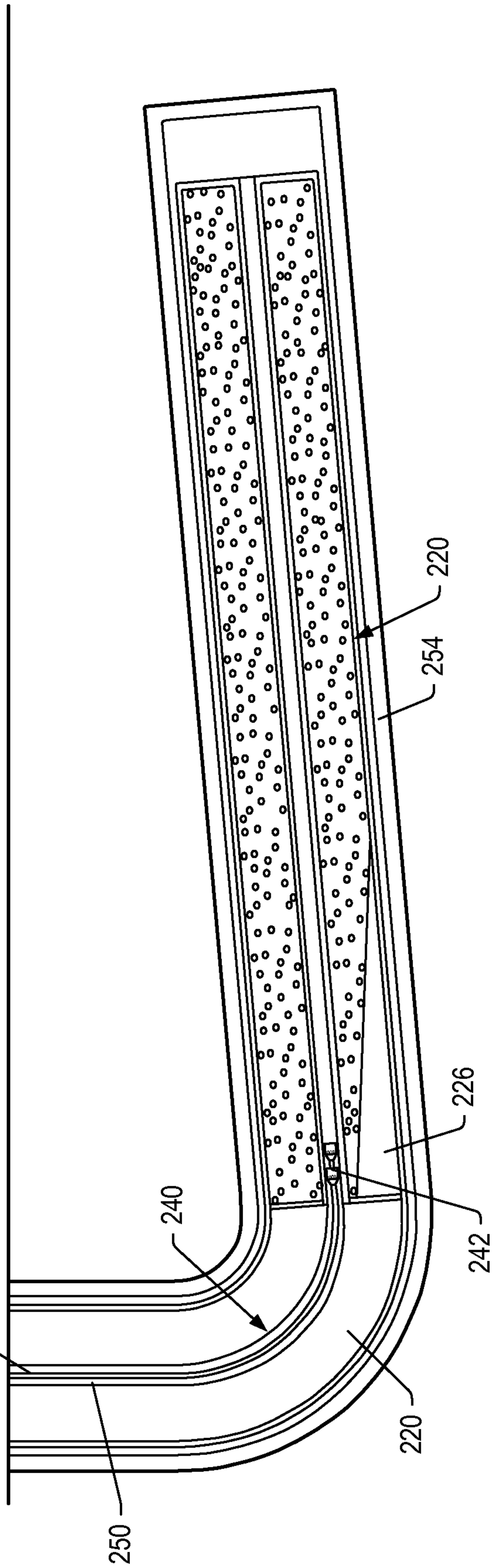

FIG. 5

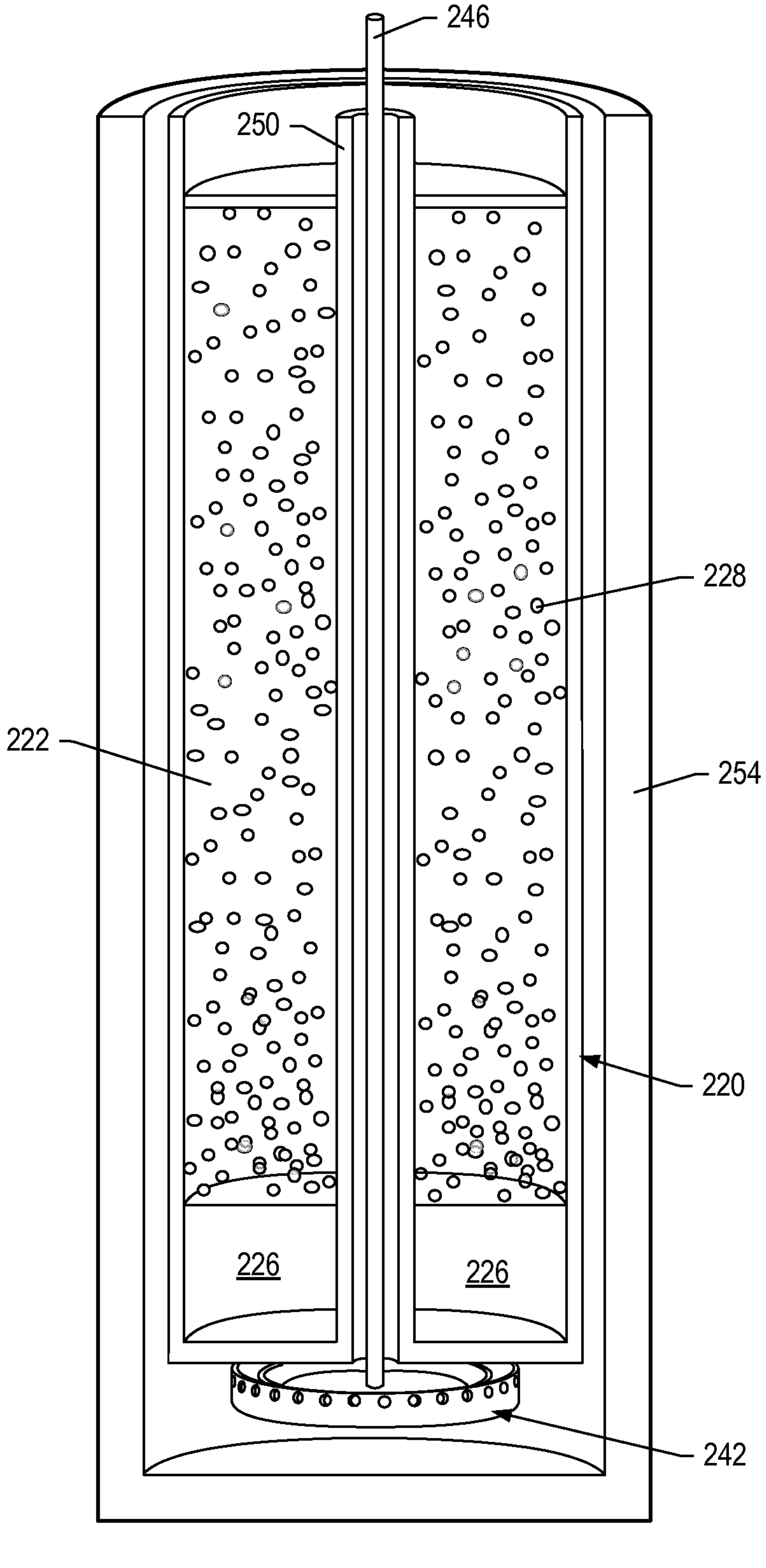

FIG. 6

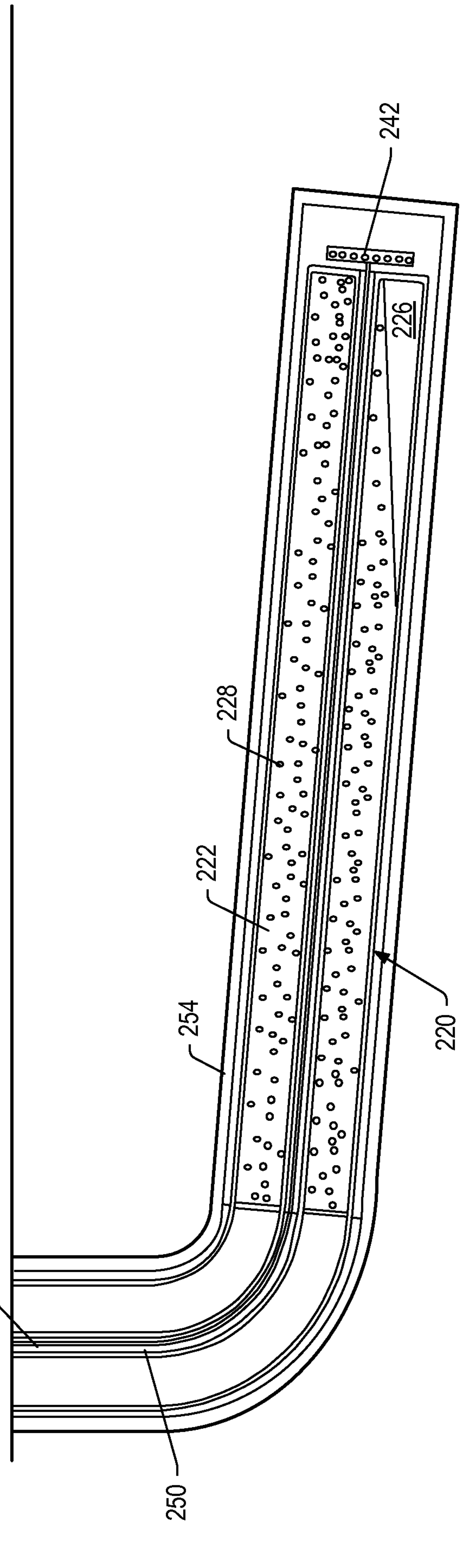

FIG. 7

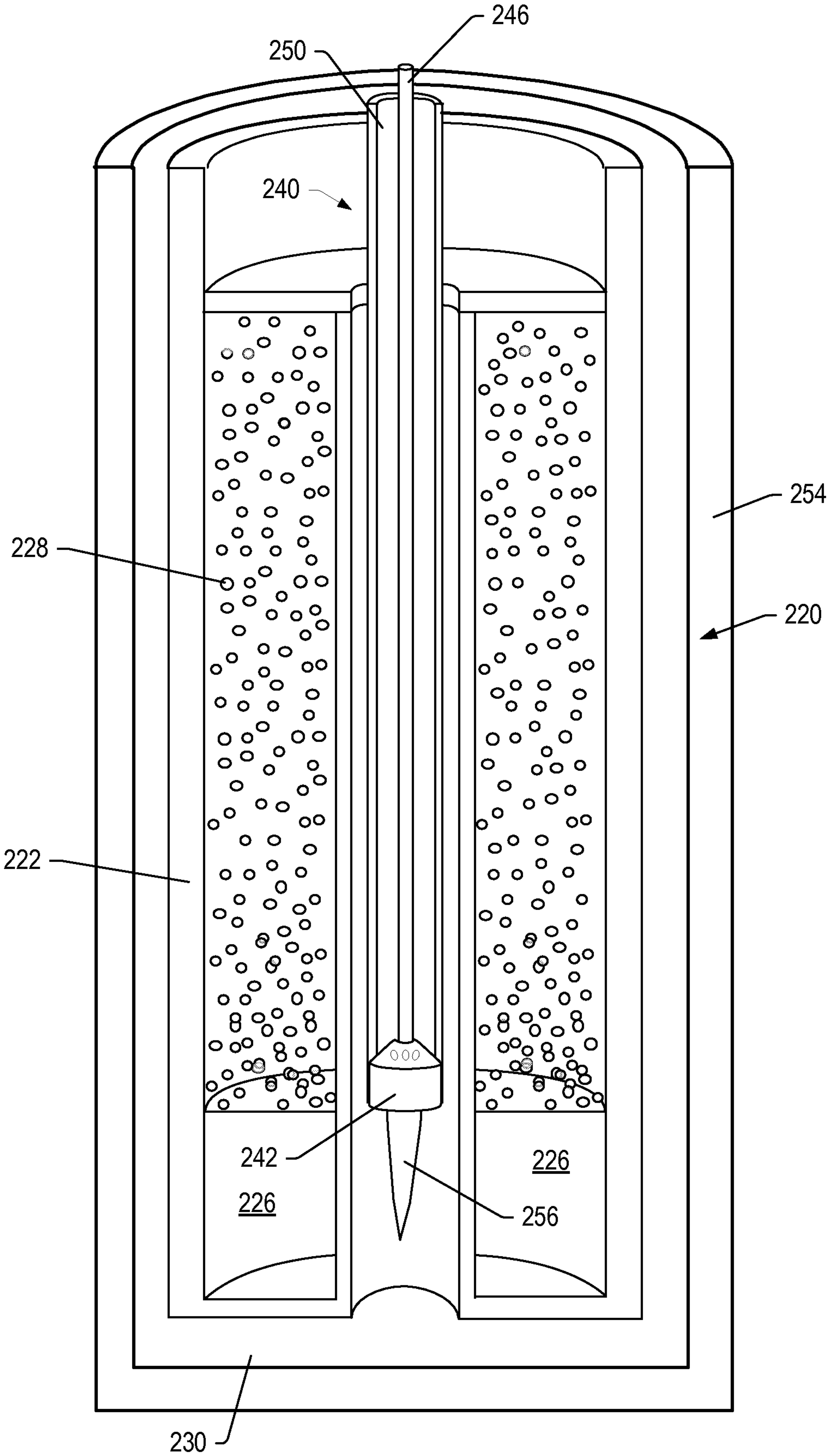

FIG. 8

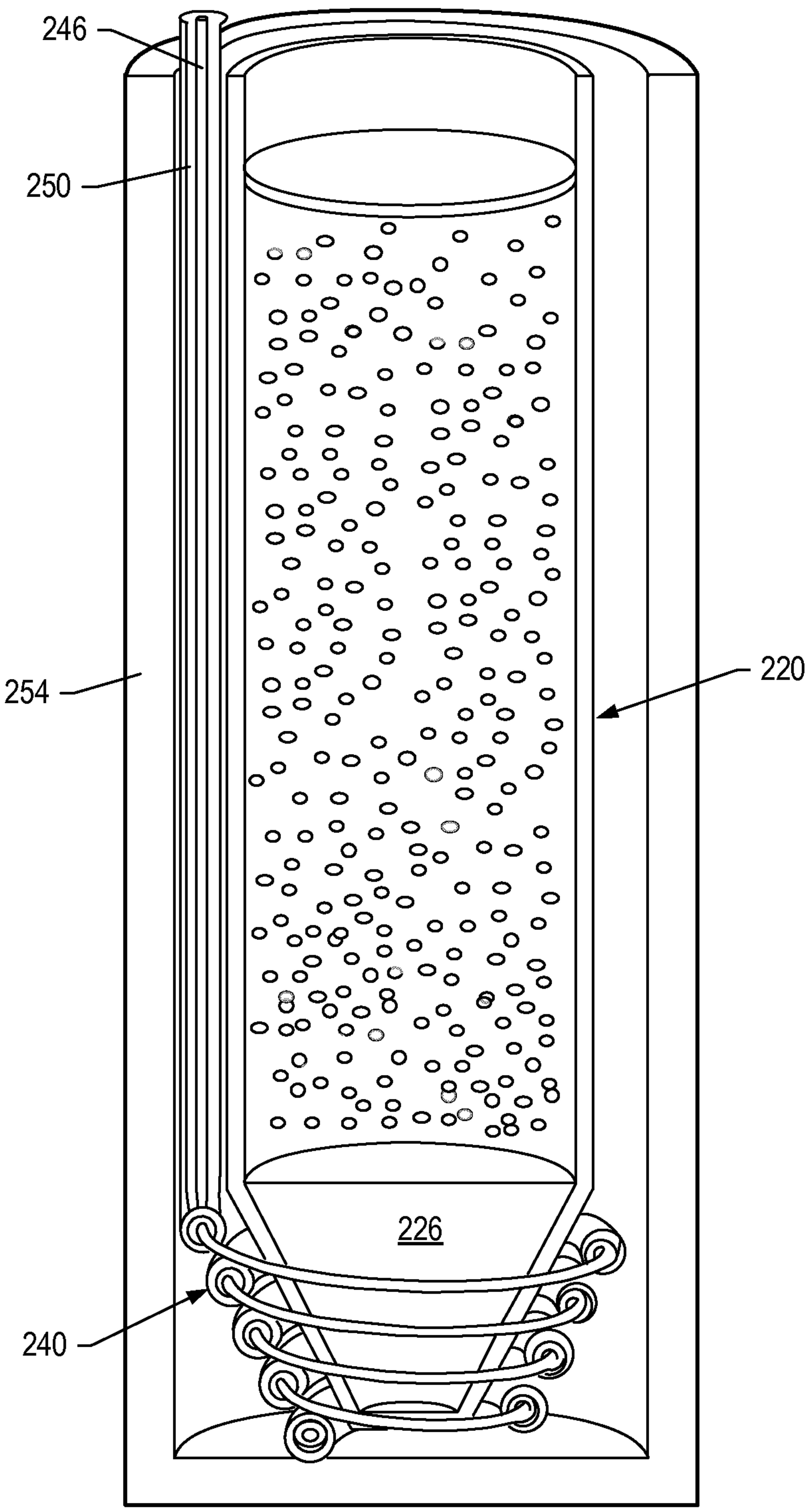

FIG. 9

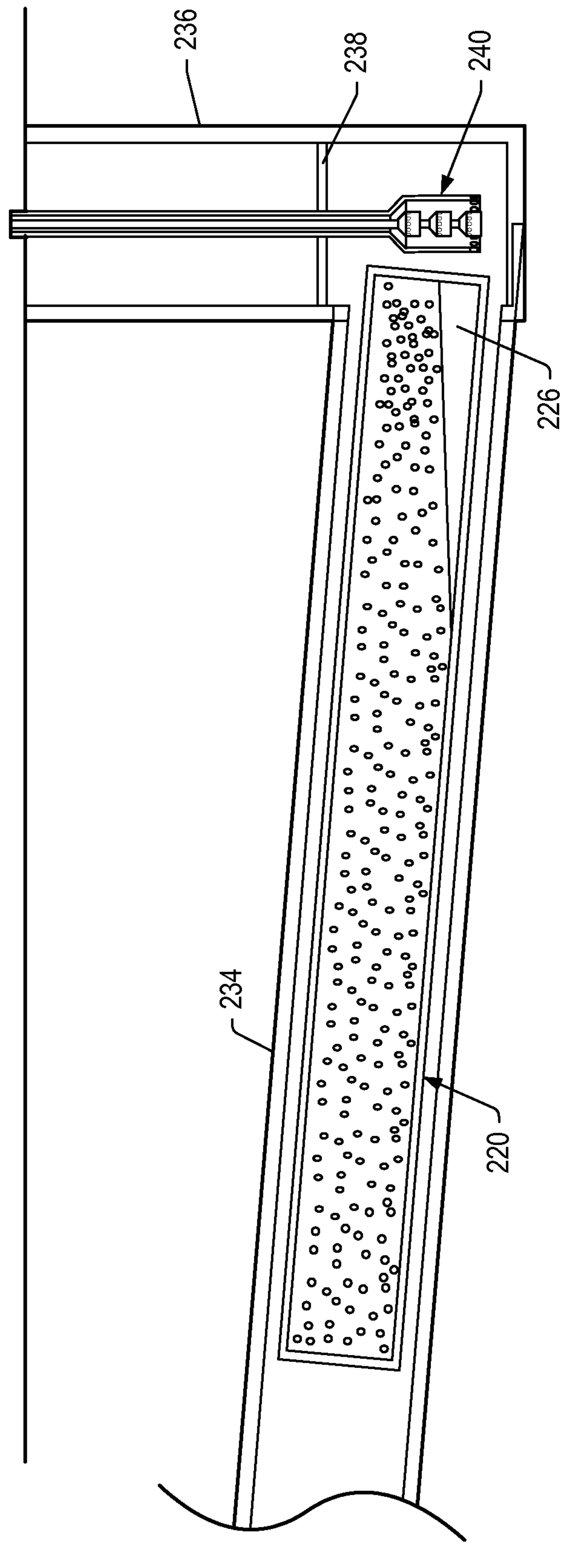

FIG. 10

FIG. 9