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

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2463110 A1 2003/05/01

(21) 2 463 110

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2002/10/24
(87) Date publication PCT/PCT Publication Date: 2003/05/01
(85) Entrée phase nationale/National Entry: 2004/04/07
(86) N° demande PCT/PCT Application No.: US 2002/034274
(87) N° publication PCT/PCT Publication No.: 2003/036041
(30) Priorités/Priorities: 2001/10/24 (60/334,568) US; 2001/10/24 (60/337,136) US; 2002/04/24 (60/374,970) US; 2002/04/24 (60/374,995) US

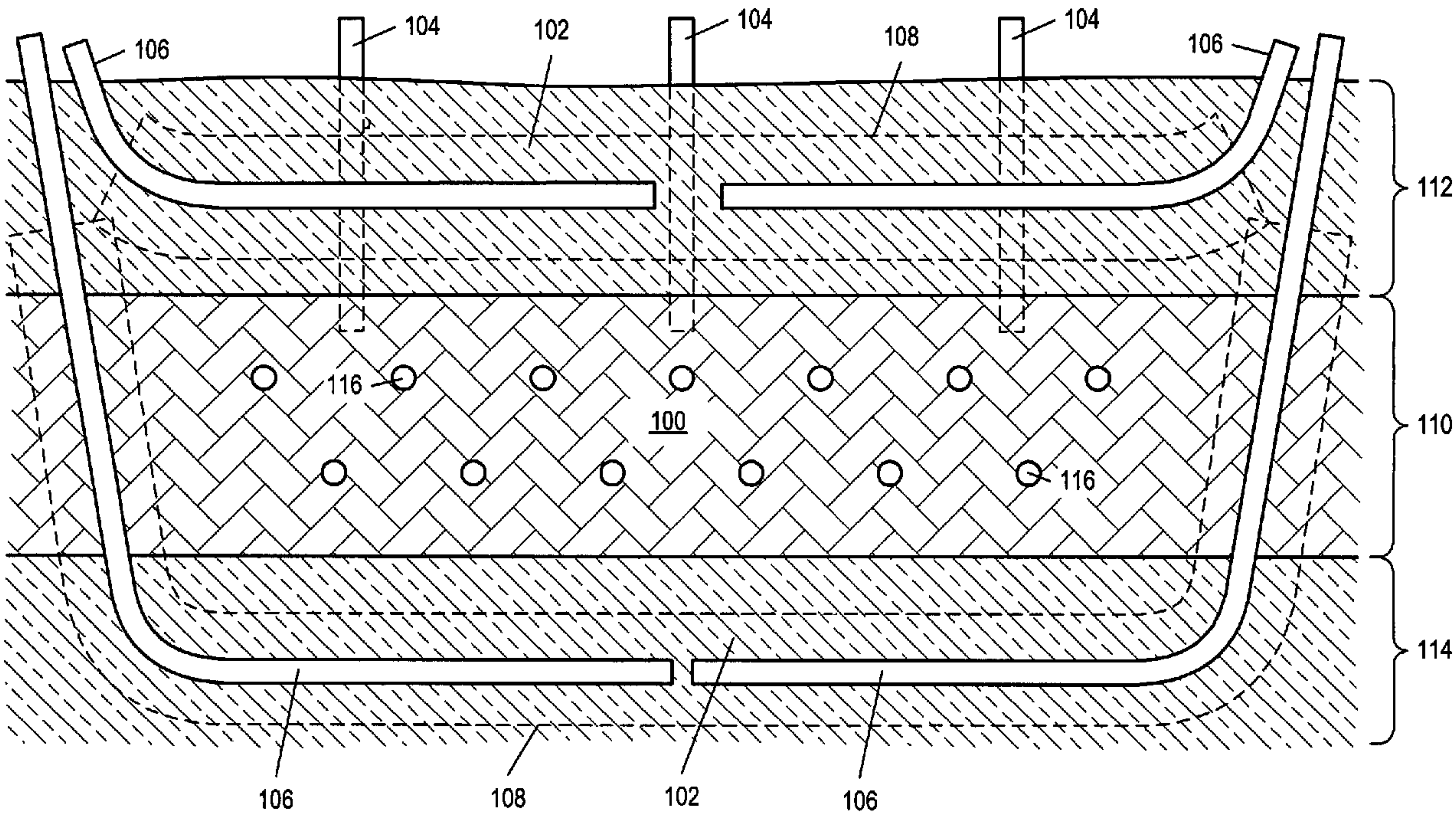
(51) Cl.Int.[7]/Int.Cl.[7] E21B 43/30, E21B 43/24, E21B 36/00

(71) Demandeur/Applicant:
SHELL CANADA LIMITED, CA

(72) Inventeurs/Inventors:
VINEGAR, HAROLD J., US;
WELLINGTON, SCOTT LEE, US;
STEGEMEIER, GEORGE LEO, US;
MAHER, KEVIN ALBERT, US;
AYMOND, DANNIE ANTOINE, US;
MCKINZIE, BILLY JOHN, US;
WARD, JOHN MICHAEL, US;
...

(74) Agent: SMART & BIGGAR

(54) Titre : RECUPERATION IN SITU DANS UNE FORMATION CONTENANT DES HYDROCARBURES AU MOYEN DE BARRIERES
(54) Title: IN SITU RECOVERY FROM A HYDROCARBON CONTAINING FORMATION USING BARRIERS



(57) Abrégé/Abstract:
A method is described for inhibiting migration of fluids into and/or out of a treatment area undergoing an in situ conversion process. Barriers in the formation proximate a treatment area may be used to inhibit migration of fluids. Inhibition of migration of fluids may occur before, during, and/or after an in situ treatment process. For example, migration of fluids may be inhibited while heat is provided from heaters to at least a portion of the treatment area. Barriers may include naturally occurring portions (e.g., overburden, and/or underburden) and/or installed portions, such as frozen barrier zones, cooled by a refrigerant.

(21) 2 463 110

(13) A1

(72) **Inventeurs(suite)/Inventors(continued)**: WATKINS, RONNIE WADE, US; PALFREYMAN, BRUCE DONALD, US

CA 02463110 2004-04-07

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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 May 2003 (01.05.2003)

PCT

(10) International Publication Number
WO 03/036041 A3

(51) International Patent Classification[7]**: E21B 43/30**, 36/00, 43/24

(21) International Application Number: PCT/US02/34274

(22) International Filing Date: 24 October 2002 (24.10.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/337,136	24 October 2001 (24.10.2001)	US
60/334,568	24 October 2001 (24.10.2001)	US
60/374,995	24 April 2002 (24.04.2002)	US
60/374,970	24 April 2002 (24.04.2002)	US

(71) Applicant *(for AE, AG, AL, AM, AT, AU, AZ, BA, BB, BE, BG, BR, BY, BZ, CH, CN, CO, CR, CU, CY, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, FR, GB, GD, GE, GH, GM, GR, HR, HU, ID, IE, IL, IN, IS, IT, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MC, MD, MG, MK, MN, MW, MX, MZ, NL, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, SZ, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW only)*: **SHELL OIL COMPANY** [US/US]; Department of Intellectual Property, One Shell Plaza, P.O. Box 2463, Houston, TX 77252-2463 (US).

(71) Applicant *(for CA only)*: **SHELL CANADA LIMITED** [CA/CA]; 400-4th Avenue, S.W., Calgary, Alberta T2P 2H5 (CA).

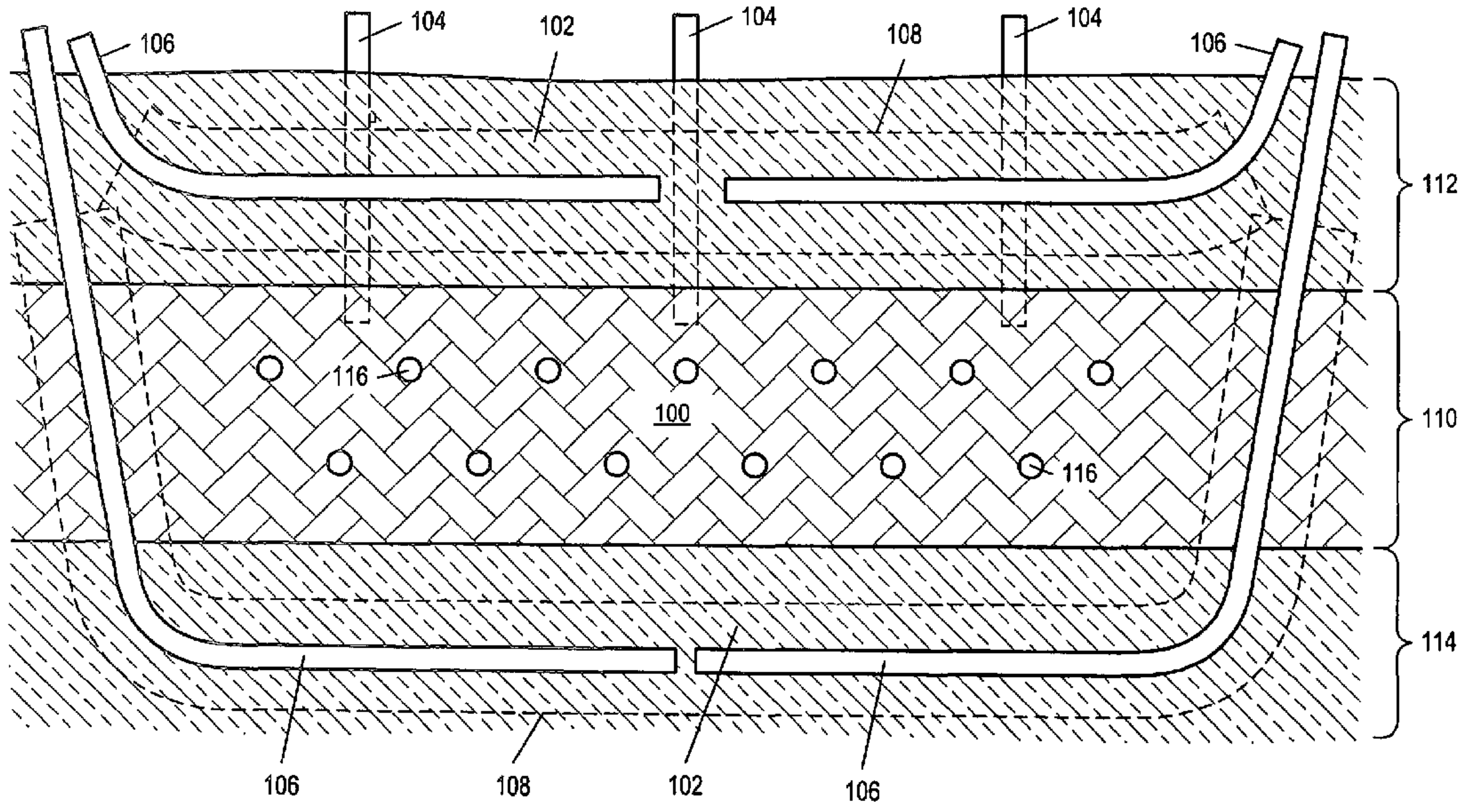
(72) Inventors: VINEGAR, Harold, J.; 4613 Laurel, Bellaire, TX 77401 (US). **WELLINGTON, Scott, Lee**; 5109 Aspen Street, Bellaire, TX 77401 (US). **STEGEMEIER, George, Leo**; 5819 Queensloch Drive, Houston, TX 77096 (US). **MAHER, Kevin, Albert**; 5106 Huisache Street, Bellaire, TX 77401 (US). **AYMOND, Dannie, Antoine**; 8002 Shangrila Lane, Houston, TX 77095 (US). **MCKINZIE, Billy, John**; 11907 Kemp Hollow Lane, Houston, TX 77043 (US). **WARD, John, Michael**; 2231 Royal Adelaide Drive, Katy, TX 77450 (US). **WATKINS, Ronnie, Wade**; 17503 Bending Cypress Road, Cypress, TX 77429 (US). **PALFREYMAN, Bruce, Donald**; 1015 Ivory Ridge Lane, Houston, TX 77094 (US).

(74) Agent: CHRISTENSEN, Del, S.; SHELL OIL COMPANY, One Shell Plaza, P.O. Box 2463, Houston, TX 77252-2463 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC,

[Continued on next page]

(54) Title: IN SITU RECOVERY FROM A HYDROCARBON CONTAINING FORMATION USING BARRIERS



(57) Abstract: A method is described for inhibiting migration of fluids into and/or out of a treatment area undergoing an in situ conversion process. Barriers in the formation proximate a treatment area may be used to inhibit migration of fluids. Inhibition of migration of fluids may occur before, during, and/or after an in situ treatment process. For example, migration of fluids may be inhibited while heat is provided from heaters to at least a portion of the treatment area. Barriers may include naturally occurring portions (e.g., overburden, and/or underburden) and/or installed portions, such as frozen barrier zones, cooled by a refrigerant.

WO 03/036041 A3

WO 03/036041 A3

LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(88) Date of publication of the international search report: 16 October 2003

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

IN SITU RECOVERY FROM A HYDROCARBON CONTAINING FORMATION USING BARRIERS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to methods and systems for treating subsurface formations. The present invention generally relates to the formation of barriers around a treatment area to inhibit migration of fluid into or out of the treatment area.

2. Description of Related Art

Hydrocarbons obtained from subterranean (e.g., sedimentary) formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available hydrocarbon resources and 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 within 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 within 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.

There has been a significant amount of effort to develop methods and systems to economically produce hydrocarbons, hydrogen, and/or other products from hydrocarbon containing formations. At present, however, there are still many hydrocarbon containing formations from which hydrocarbons, hydrogen, and/or other products cannot be economically produced. Thus, there is still a need for improved methods and systems for production of hydrocarbons, hydrogen, and/or other products from various hydrocarbon containing formations.

Some hydrocarbon containing formations include natural geographic features that inhibit fluid migration into or out of the hydrocarbon containing formation. Some hydrocarbon containing formations may allow migration of fluids into and/or out of the hydrocarbon containing formations. Fluid migration into or out of a hydrocarbon containing formation that is to be used to produce desirable products may need to be inhibited to allow for economical and environmentally favorable use of the hydrocarbon containing formation.

SUMMARY OF THE INVENTION

In an embodiment, hydrocarbons within a hydrocarbon containing formation (e.g., a formation containing coal, oil shale, heavy hydrocarbons, or a combination thereof) may be converted in situ within the formation to yield a mixture of relatively high quality hydrocarbon products, hydrogen, and/or other products. Heat sources may be used to heat a portion of the hydrocarbon containing formation to temperatures that allow pyrolysis of the hydrocarbons. In some embodiments, synthesis gas may be produced from a hydrocarbon containing formation in situ.

Hydrocarbons, hydrogen, and other formation fluids may be removed from the formation through production wells. In some embodiments, formation fluids may be removed in a vapor phase. In other embodiments, formation fluids may be removed in liquid and vapor phases or in a liquid phase. Temperature and pressure in at least a portion of the formation may be controlled during pyrolysis to yield improved products from the formation.

In some embodiments, migration of fluids into and/or out of a treatment area may be inhibited. Inhibition of migration of fluids may occur before, during, and/or after an in situ treatment process. For example, migration of fluids may be inhibited while heat is provided from heat sources to at least a portion of the treatment area. Barriers may be used to inhibit migration of fluids into and/or out of a treatment area in a formation. Barriers may include, but are not limited to naturally occurring portions and/or installed portions. In some embodiments, the barrier is a low temperature zone or frozen barrier formed by freeze wells installed around a perimeter of a treatment area.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 1 depicts a plan view representation of an embodiment of treatment areas formed by perimeter barriers.

FIG. 2 depicts a side representation of an embodiment of an in situ conversion process system used to treat a thin rich formation.

FIG. 3 depicts a side representation of an embodiment of an in situ conversion process system.

FIG. 4 depicts a side representation of an embodiment of an in situ conversion process system with an installed upper perimeter barrier and an installed lower perimeter barrier.

FIG. 5 depicts a plan view representation of an embodiment of treatment areas formed by perimeter barriers having arced portions, wherein the centers of the arced portions are in an equilateral triangle pattern.

FIG. 6 depicts a plan view representation of an embodiment of treatment areas formed by perimeter barriers radially positioned around a central point.

FIG. 7 depicts a plan view representation of a portion of a treatment area defined by a double ring of freeze wells.

FIG. 8 depicts a side representation of a freeze well that is directionally drilled in a formation so that the freeze well enters the formation in a first location and exits the formation in a second location.

FIG. 9 depicts a side representation of freeze wells that form a barrier along sides and ends of a dipping hydrocarbon containing layer in a formation.

FIG. 10 depicts a representation of an embodiment of a freeze well and an embodiment of a heat source that may be used during an in situ conversion process.

FIG. 11 depicts an embodiment of a freeze well for inhibiting water flow.

FIG. 12 depicts an embodiment of a freeze well for a hydrocarbon containing formation.

FIG. 13 depicts an embodiment of a treatment area surrounded by two rings of freeze wells and a ring of monitoring wells.

FIG. 14 depicts an embodiment of a treatment area surrounded by a ring of dewatering wells.

FIG. 15 depicts an embodiment of a treatment area surrounded by two rings of dewatering wells.

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

DETAILED DESCRIPTION OF THE INVENTION

The following description generally relates to systems and methods for treating a hydrocarbon containing formation (e.g., a formation containing coal (including lignite, sapropelic coal, etc.), oil shale, carbonaceous shale, shungites, kerogen, bitumen, oil, kerogen and oil in a low permeability matrix, heavy hydrocarbons, asphaltites, natural mineral waxes, formations wherein kerogen is blocking production of other hydrocarbons, etc.). Such formations may be treated to yield relatively high quality hydrocarbon products, hydrogen, and other products.

"Hydrocarbons" are 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 within or adjacent to mineral matrices within 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 (e.g., hydrogen ("H_2"), nitrogen ("N_2"), carbon monoxide, carbon dioxide, hydrogen sulfide, water, and ammonia).

A "formation" includes one or more hydrocarbon containing layers, one or more non-hydrocarbon layers, an overburden, and/or an underburden. An "overburden" and/or an "underburden" includes one or more different types of impermeable materials. For example, overburden and/or underburden may include rock, shale, mudstone, or wet/tight carbonate (i.e., an impermeable carbonate without hydrocarbons). In some embodiments of in situ conversion processes, an overburden and/or an 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 results in significant characteristic changes of the hydrocarbon containing layers of the overburden and/or underburden. For example, an underburden may contain shale or mudstone. In some cases, the overburden and/or underburden may be somewhat permeable.

The terms "formation fluids" and "produced fluids" refer to fluids removed from a hydrocarbon containing formation and may include pyrolyzation fluid, synthesis gas, mobilized hydrocarbon, and water (steam). The term "mobilized fluid" refers to fluids within the formation that are able to flow because of thermal treatment of the formation. Formation fluids may include hydrocarbon fluids as well as non-hydrocarbon fluids.

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 within a conduit. A heat source may also include heat sources that generate heat by burning a fuel external to or within a formation, such as surface burners, downhole gas burners, flameless distributed combustors, and natural distributed combustors. In addition, it is envisioned that 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 media 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. 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 (e.g., chemical reactions, solar energy, wind energy, biomass, or other sources of renewable energy). A chemical reaction may include an exothermic reaction (e.g., an oxidation reaction). A heat source may include a heater that provides heat to a zone proximate and/or surrounding a heating location such as a heater well.

A "heater" is any system 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 (e.g., natural distributed combustors), and/or combinations thereof. A "unit of heat sources" refers to a number of heat sources that form a template that is repeated to create a pattern of heat sources within a formation.

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 other cross-sectional shapes (e.g., circles, ovals, squares, rectangles, triangles, slits, or other regular or irregular shapes). As used herein, the terms "well" and "opening," when referring to an opening in the formation, may be used interchangeably with the term "wellbore."

"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.

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

"Dipping" refers to a formation that slopes downward or inclines from a plane parallel to the earth's surface, assuming the plane is flat (i.e., a "horizontal" plane). A "dip" is an angle that a stratum or similar feature makes with a horizontal plane. A "steeply dipping" hydrocarbon containing formation refers to a hydrocarbon containing formation lying at an angle of at least 20° from a horizontal plane. "Down dip" refers to downward along a direction parallel to a dip in a formation. "Up dip" refers to upward along a direction parallel to a dip of a formation. "Strike" refers to the course or bearing of hydrocarbon material that is normal to the direction of dip.

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

Hydrocarbons within a hydrocarbon containing formation (e.g., a formation containing coal, oil shale, heavy hydrocarbons, or a combination thereof) may be converted in situ to yield a mixture of relatively high quality hydrocarbon products, hydrogen, and/or other products. Heat sources may be used to heat a portion of the hydrocarbon containing formation to temperatures that allow pyrolysis of the hydrocarbons. Hydrocarbons, hydrogen, and other formation fluids may be removed from the formation through one or more production wells. Barriers may be used to inhibit migration of fluids (e.g., generated fluids and/or groundwater) into and/or out of a portion of a formation undergoing an in situ conversion process. Barriers may be provided to the portion of the formation prior to, during, and/or after providing heat from one or more heat sources to the treatment area. For example, a barrier may be provided to a portion of the formation that has previously undergone a conversion process.

A volume of a formation that is, is to be, or has been, subjected to an in situ conversion process may be referred to as a treatment area. In some embodiments, barriers may define the treatment area. Alternatively, barriers may be provided to a portion of the treatment area. Barriers may include, but are not limited to naturally occurring portions (e.g., overburden and/or underburden), freeze wells, frozen barrier zones, low temperature barrier zones, grout walls, sulfur wells, dewatering wells, injection wells, a barrier formed by a gel produced in the formation, a barrier formed by precipitation of salts in the formation, a barrier formed by a polymerization reaction in the formation, sheets driven into the formation, or combinations thereof.

Naturally occurring portions of the formation that form part of a perimeter barrier may include substantially impermeable layers of the formation. In some embodiments, installed portions of the perimeter barrier may be formed as needed to define separate treatment areas. In situ conversion process (ICP) wells may be placed within treatment areas. ICP wells may include heat sources, production wells, treatment area dewatering wells, monitor wells, and other types of wells used during in situ conversion.

An in situ conversion process for hydrocarbons may include providing heat to a portion of a hydrocarbon containing formation and controlling a temperature, rate of temperature increase, and/or pressure within the heated portion. A temperature and/or a rate of temperature increase of the heated portion may be controlled by altering the energy supplied to heat sources in the formation.

Controlling pressure and temperature within a hydrocarbon containing formation may allow properties of the produced formation fluids to be controlled. For example, composition and quality of formation fluids produced from the formation may be altered by altering an average pressure and/or an average temperature in a selected section of a heated portion of the formation. The quality of the produced fluids may be evaluated based on characteristics of the fluid such as, but not limited to, API gravity, percent olefins in the produced formation fluids, ethene to ethane ratio, atomic hydrogen to carbon ratio, percent of hydrocarbons within produced formation fluids having carbon numbers greater than 25, total equivalent production (gas and liquid), total liquids production, and/or liquid yield as a percent of Fischer Assay.

In an in situ conversion process embodiment, pressure may be increased within a selected section of a portion of a hydrocarbon containing formation to a selected pressure during pyrolysis. A selected pressure may be within a range from about 2 bars absolute to about 72 bars absolute or, in some embodiments, 2 bars absolute to 36 bars absolute. Alternatively, a selected pressure may be within a range from about 2 bars absolute to about 18 bars absolute. In some in situ conversion process embodiments, a majority of hydrocarbon fluids may be produced from a formation having a pressure within a range from about 2 bars absolute to about 18 bars absolute. The pressure during pyrolysis may vary or be varied. The pressure may be varied to alter and/or control a composition of a formation fluid produced, to control a percentage of condensable fluid as compared to non-condensable fluid, and/or to control an API gravity of 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.

Heating the formation from heat sources placed in the formation may allow a permeability of the heated portion of a hydrocarbon containing formation to be substantially uniform. A substantially uniform permeability may inhibit channeling of formation fluids in the formation and allow production from substantially all portions of the heated formation. An assessed (e.g., calculated or estimated) permeability of any selected portion in the formation having a substantially uniform permeability may not vary by more than a factor of 10 from an assessed average permeability of the selected portion.

Permeability of a selected section within the heated portion of the hydrocarbon containing formation may rapidly increase when the selected section is heated. A permeability of an impermeable hydrocarbon containing formation may be less than about 0.1 millidarcy (9.9×10^{-17} m^2) before treatment. In some embodiments, pyrolyzing at least a portion of a hydrocarbon containing formation may increase a permeability within a selected section of the portion to greater than about 10 millidarcy, 100 millidarcy, 1 darcy, 10 darcy, 20 darcy, or 50 darcy.

A permeability of a selected section of the portion may increase by a factor of more than about 100, 1,000, 10,000, 100,000 or more.

FIG. 1 depicts an embodiment of treatment areas 100 surrounded by perimeter barrier 102. Each treatment area 100 may be a volume of formation that is, or is to be, subjected to an in situ conversion process. Perimeter barrier 102 may include installed portions and naturally occurring portions of the formation. Naturally occurring portions of the formation that form part of a perimeter barrier may include substantially impermeable layers of the formation. Examples of naturally occurring perimeter barriers include overburdens and underburdens. Installed portions of perimeter barrier 102 may be formed as needed to define separate treatment areas 100.

In situ conversion process (ICP) wells 104 may be placed within treatment areas 100. ICP wells 104 may include heat sources, production wells, treatment area dewatering wells, monitor wells, and other types of wells used during in situ conversion. As shown in FIG. 1, freeze wells 106 form low temperature zones 108 around treatment areas 100.

Different treatment areas 100 may share common barrier sections to minimize the length of perimeter barrier 102 that needs to be formed. Perimeter barrier 102 may inhibit fluid migration into treatment area 100 undergoing in situ conversion. Advantageously, perimeter barrier 102 may inhibit formation water from migrating into treatment area 100. Formation water typically includes water and dissolved material in the water (e.g., salts). If formation water were allowed to migrate into treatment area 100 during an in situ conversion process, the formation water might increase operating costs for the process by adding additional energy costs associated with vaporizing the formation water and additional fluid treatment costs associated with removing, separating, and treating additional water in formation fluid produced from the formation. A large amount of formation water migrating into a treatment area may inhibit heat sources from raising temperatures within portions of treatment area 100 to desired temperatures.

Perimeter barrier 102 may inhibit undesired migration of formation fluids out of treatment area 100 during an in situ conversion process. Perimeter barriers 102 between adjacent treatment areas 100 may allow adjacent treatment areas to undergo different in situ conversion processes. For example, a first treatment area may be undergoing pyrolysis, a second treatment area adjacent to the first treatment area may be undergoing synthesis gas generation, and a third treatment area adjacent to the first treatment area and/or the second treatment area may be subjected to an in situ solution mining process. Operating conditions within the different treatment areas may be at different temperatures, pressures, production rates, heat injection rates, etc.

Perimeter barrier 102 may define a limited volume of formation that is to be treated by an in situ conversion process. The limited volume of formation is known as treatment area 100. Defining a limited volume of formation that is to be treated may allow operating conditions within the limited volume to be more readily controlled. In some formations, a hydrocarbon containing layer that is to be subjected to in situ conversion is located in a portion of the formation that is permeable and/or fractured. Without perimeter barrier 102, formation fluid produced during in situ conversion might migrate out of the volume of formation being treated. Flow of formation fluid out of the volume of formation being treated may inhibit the ability to maintain a desired pressure within the portion of the formation being treated. Thus, defining a limited volume of formation that is to be treated by using perimeter barrier 102 may allow the pressure within the limited volume to be controlled. Controlling the amount of fluid removed from treatment area 100 through pressure relief wells, production wells and/or heat sources may allow pressure within the treatment area to be controlled. In some embodiments, pressure relief wells are perforated casings placed within or adjacent to wellbores of heat sources that have sealed casings, such as flameless distributed combustors. The use of some types of perimeter barriers (e.g., frozen barriers and grout walls) may allow pressure control in individual treatment areas 100.

Uncontrolled flow or migration of formation fluid out of treatment area 100 may adversely affect the ability to efficiently maintain a desired temperature within treatment area 100. Perimeter barrier 102 may inhibit migration of hot formation fluid out of treatment area 100. Inhibiting fluid migration through the perimeter of treatment area 100 may limit convective heat losses to heat loss in fluid removed from the formation through production wells and/or fluid removed to control pressure within the treatment area.

During in situ conversion, heat applied to the formation may cause fractures to develop within treatment area 100. Some of the fractures may propagate towards a perimeter of treatment area 100. A propagating fracture may intersect an aquifer and allow formation water to enter treatment area 100. Formation water entering treatment area 100 may not permit heat sources in a portion of the treatment area to raise the temperature of the formation to temperatures significantly above the vaporization temperature of formation water entering the formation. Fractures may also allow formation fluid produced during in situ conversion to migrate away from treatment area 100.

Perimeter barrier 102 around treatment area 100 may limit the effect of a propagating fracture on an in situ conversion process. In some embodiments, perimeter barriers 102 are located far enough away from treatment areas 100 so that fractures that develop in the formation do not influence perimeter barrier integrity. Perimeter barriers 102 may be located over 10 m, 40 m, or 70 m away from ICP wells 104. In some embodiments, perimeter barrier 102 may be located adjacent to treatment area 100. For example, a frozen barrier formed by freeze wells 106 may be located close to heat sources, production wells, or other wells. ICP wells 104 may be located less than 1 m away from freeze wells, although a larger spacing may advantageously limit influence of the frozen barrier on the ICP wells, and limit the influence of formation heating on the frozen barrier.

In some perimeter barrier embodiments, and especially for natural perimeter barriers, ICP wells 104 may be placed in perimeter barrier 102 or next to the perimeter barrier. For example, ICP wells 104 may be used to treat hydrocarbon layer 110 that is a thin rich hydrocarbon layer. The ICP wells may be placed in overburden 112 and/or underburden 114 adjacent to hydrocarbon layer 110, as depicted in FIG. 2. ICP wells 104 may include heater-production wells that heat the formation and remove fluid from the formation. Thin rich layer hydrocarbon layer 110 may have a thickness greater than about 0.2 m and less than about 8 m, and a richness of from about 205 liters of oil per metric ton to about 1670 liters of oil per metric ton. Overburden 112 and underburden 114 may be portions of perimeter barrier 102 for the in situ conversion system used to treat rich thin layer 110. Heat losses to overburden 112 and/or underburden 114 may be acceptable to produce rich hydrocarbon layer 110. In other ICP well placement embodiments for treating thin rich hydrocarbon layers, ICP wells may be placed within the thin hydrocarbon layer or hydrocarbon layers.

In some in situ conversion process embodiments, a perimeter barrier may be self-sealing. For example, formation water adjacent to a frozen barrier formed by freeze wells may freeze and seal the frozen barrier should the frozen barrier be ruptured by a shift or fracture in the formation. In some in situ conversion process embodiments, progress of fractures in the formation may be monitored. If a fracture that is propagating towards the perimeter of the treatment area is detected, a controllable parameter (e.g., pressure or energy input) may be adjusted to inhibit propagation of the fracture to the surrounding perimeter barrier.

Perimeter barriers may be useful to address regulatory issues and/or to insure that areas proximate a treatment area (e.g., water tables or other environmentally sensitive areas) are not substantially affected by an in situ conversion process. The formation within the perimeter barrier may be treated using an in situ conversion process.

The perimeter barrier may inhibit the formation on an outer side of the perimeter barrier from being affected by the in situ conversion process used on the formation within the perimeter barrier. Perimeter barriers may inhibit fluid migration from a treatment area. Perimeter barriers may inhibit rise in temperature to pyrolysis temperatures on outer sides of the perimeter barriers.

Different types of barriers may be used to form a perimeter barrier around an in situ conversion process treatment area. The perimeter barrier may be, but is not limited to, a frozen barrier surrounding the treatment area, dewatering wells, a grout wall formed in the formation, a sulfur cement barrier, a barrier formed by a gel produced in the formation, a barrier formed by precipitation of salts in the formation, a barrier formed by a polymerization reaction in the formation, sheets driven into the formation, or combinations thereof.

FIG. 3 depicts a side representation of a portion of an embodiment of treatment area 100 having perimeter barrier 102 formed by overburden 112, underburden 114, and freeze wells 106 (only one freeze well is shown in FIG. 3). A portion of freeze well 106 and perimeter barrier 102 formed by the freeze well extend into underburden 114. Portions of heat sources 116 and portions of production wells 118 may pass through low temperature zone 108 formed by freeze wells 106. In some embodiments, perimeter barrier 102 may not extend into underburden 114 (e.g., a perimeter barrier may extend into hydrocarbon layer 110 reasonably close to the underburden or some of the hydrocarbon layer may function as part of the perimeter barrier). Underburden 114 may be a rock layer that inhibits fluid flow into or out of treatment area 100. In some embodiments, a portion of the underburden may be hydrocarbon containing material that is not to be subjected to in situ conversion.

Overburden 112 may extend over treatment area 100. Overburden 112 may include a portion of hydrocarbon containing material that is not to be subjected to in situ conversion. Overburden 112 may inhibit fluid flow into or out of treatment area 100.

Some formations may include underburden 114 that is permeable or includes fractures that would allow fluid flow into or out of treatment area 100. A portion of perimeter barrier 102 may be formed below treatment area 100 to inhibit inflow of fluid into the treatment area and/or to inhibit outflow of formation fluid during in situ conversion.

If a large amount of water is present in the hydrocarbon containing material, dewatering wells 120 may be used to remove water in the treatment area after a perimeter barrier is formed. If the hydrocarbon containing material does not contain a large amount of water, heat sources may be activated. The heat sources may vaporize water within the formation, and the water vapor may be removed from the treatment area through production wells.

FIG. 4 depicts treatment area 100 having a portion of perimeter barrier 102 that is below the treatment area. The perimeter barrier may be a frozen barrier formed by freeze wells 106. In some embodiments, a perimeter barrier below a treatment area may follow along a geological formation (e.g., along dip of a dipping coal formation).

Some formations may include overburden 112 that is permeable or includes fractures that allow fluid flow into or out of treatment area 100. A portion of perimeter barrier 102 may be formed above the treatment area to inhibit inflow of fluid into the treatment area and/or to inhibit outflow of formation fluid during in situ conversion. FIG. 4 depicts an embodiment of an in situ conversion process having a portion of perimeter barrier 102 formed above treatment area 100. In some embodiments, a perimeter barrier above a treatment area may follow along a geological formation (e.g., along dip of a dipping formation). In some embodiments, a perimeter barrier above a treatment area may be formed as a ground cover placed at or near the surface of the formation. Such a perimeter barrier may allow for treatment of a formation wherein a hydrocarbon layer to be processed is close to the surface.

A perimeter barrier may have any desired shape. In some embodiments, portions of perimeter barriers may follow along geological features and/or property lines. In some embodiments, portions of perimeter barriers may have circular, square, rectangular, or polygonal shapes. Portions of perimeter barriers may also have irregular shapes. A perimeter barrier having a circular shape may advantageously enclose a larger area than other regular polygonal shapes that have the same perimeter. For example, for equal perimeters, a circular barrier will enclose about 27% more area than a square barrier. Using a circular perimeter barrier may require fewer wells and/or less material to enclose a desired area with a perimeter barrier than would other regular perimeter barrier shapes. In some embodiments, square, rectangular or other polygonal perimeter barriers are used to conform to property lines and/or to accommodate a regular well pattern of heat sources and production wells.

FIG. 5 depicts a plan view representation of a perimeter barrier embodiment that forms treatment areas 100 in a formation. Centers of arced portions of perimeter barriers 102 are positioned at apices of imaginary equilateral triangles. The imaginary equilateral triangles are depicted as dashed lines. First circular barrier 102' may be formed in the formation to define first treatment area 100'.

Second barrier 102" may be formed. Second barrier 102" and portions of first barrier 102' may define second treatment area 100". Second barrier 102" may have an arced portion with a radius that is substantially equal to the radius of first circular barrier 102'. The center of second barrier 102" may be located such that if the second barrier were formed as a complete circle, the second barrier would contact the first barrier substantially at a tangent point. Second barrier 102" may include linear sections 122 that allow for a larger area to be enclosed for the same or a lesser length of perimeter barrier than would be needed to complete the second barrier as a circle. In some embodiments, second barrier 102" may not include linear sections and the second barrier may contact the first barrier at a tangent point or at a tangent region. Second treatment area 100" may be defined by portions of first circular barrier 102' and second barrier 102". The area of second treatment area 100" may be larger than the area of first treatment area 100'.

Third barrier 102"' may be formed adjacent to first barrier 102' and second barrier 102". Third barrier 102"' may be connected to first barrier 102' and second barrier 102" to define third treatment area 100"'. Additional barriers may be formed to form treatment areas for processing desired portions of a formation.

FIG. 6 depicts an embodiment of a barrier configuration in which perimeter barriers 102 are formed radially about a central point. In an embodiment, surface facilities for processing production fluid removed from the formation are located within central area 124 defined by first barrier 102'. Locating the surface facilities in the center may reduce the total length of piping needed to transport formation fluid to the treatment facilities. In alternate embodiments, ICP wells are installed in the central area and surface facilities are located outside of the pattern of barriers.

A ring of formation between second barrier 102" and first barrier 102' may be treatment area 100'. Third barrier 102"' may be formed around second barrier 102". The pattern of barriers may be extended as needed. A ring of formation between an inner barrier and an outer barrier may be a treatment area. If the area of a ring is too large to be treated as a whole, linear sections 122 extending from the inner barrier to the outer barrier may be formed to divide the ring into a number of treatment areas. In some embodiments, distances between barrier rings may be substantially the same. In other embodiments, a distance between barrier rings may be varied to adjust the area enclosed by the barriers.

In some embodiments of in situ conversion processes, formation water may be removed from a treatment area before, during, and/or after formation of a barrier around the formation. Heat sources, production wells, and other ICP wells may be installed in the formation before, during, or after formation of the barrier. Some of the production wells may be coupled to pumps that remove formation water from the treatment area. In other embodiments, dewatering wells may be formed within the treatment area to remove formation water from the treatment area. Removing formation water from the treatment area prior to heating to pyrolysis temperatures for in situ conversion may reduce the energy needed to raise portions of the formation within the treatment area to pyrolysis temperatures by eliminating the need to vaporize all formation water initially within the treatment area.

In some embodiments of in situ conversion processes, freeze wells may be used to form a low temperature zone around a portion of a treatment area. "Freeze well" refers to a well or opening in a formation used to cool a portion of the formation. In some embodiments, the cooling may be sufficient to cause freezing of materials (e.g., formation water) that may be present in the formation. In other embodiments, the cooling may not cause freezing to occur; however, the cooling may serve to inhibit the flow of fluid into or out of a treatment area by filling a portion of the pore space with liquid fluid.

In some embodiments, freeze wells may be maintained at temperatures significantly colder than a freezing temperature of formation water. Heat may transfer from the formation to the freeze wells so that a low temperature zone is formed around the freeze wells. A portion of formation water that is in, or flows into, the low temperature zone may freeze to form a barrier to fluid flow. Freeze wells may be spaced and operated so that the low temperature zone formed by each freeze well overlaps and connects with a low temperature zone formed by at least one adjacent freeze well.

Sections of freeze wells that are able to form low temperature zones may be only a portion of the overall length of the freeze wells. For example, a portion of each freeze well may be insulated adjacent to an overburden so that heat transfer between the freeze wells and the overburden is inhibited. The freeze wells may form a low temperature zone along sides of a hydrocarbon containing portion of the formation. The low temperature zone may extend above and/or below a portion of the hydrocarbon containing layer to be treated by in situ conversion. The ability to use only portions of freeze wells to form a low temperature zone may allow for economic use of freeze wells when forming barriers for treatment areas that are relatively deep within the formation.

A perimeter barrier formed by freeze wells may have several advantages over perimeter barriers formed by other methods. A perimeter barrier formed by freeze wells may be formed deep within the ground. A perimeter barrier formed by freeze wells may not require an interconnected opening around the perimeter of a treatment area. An interconnected opening is typically needed for grout walls and some other types of perimeter barriers. A perimeter barrier formed by freeze wells develops due to heat transfer, not by mass transfer. Gel, polymer, and some other types of perimeter barriers depend on mass transfer within the formation to form the perimeter barrier. Heat transfer in a formation may vary throughout a formation by a relatively small amount (e.g., typically by less than a factor of 2 within a formation layer). Mass transfer in a formation may vary by a much greater amount throughout a formation (e.g., by a factor of 10^8 or more within a formation layer). A perimeter barrier formed by freeze wells may have greater integrity and be easier to form and maintain than a perimeter barrier that needs mass transfer to form.

A perimeter barrier formed by freeze wells may provide a thermal barrier between different treatment areas and between surrounding portions of the formation that are to remain untreated. The thermal barrier may allow adjacent treatment areas to be subjected to different processes. The treatment areas may be operated at different pressures, temperatures, heating rates, and/or formation fluid removal rates. The thermal barrier may inhibit hydrocarbon material on an outer side of the barrier from being pyrolyzed when the treatment area is heated.

Forming a frozen perimeter barrier around a treatment area with freeze wells may be more economical and beneficial over the life of an in situ conversion process than operating dewatering wells around the treatment area. Freeze wells may be less expensive to install, operate, and maintain than dewatering wells. Casings for dewatering wells may need to be formed of corrosion resistant metals to withstand corrosion from formation water over the life of an in situ conversion process. Freeze wells may be made of carbon steel. Dewatering wells may enhance the spread of formation fluid from a treatment area. Water produced from dewatering wells may contain a portion of formation fluid. Such water may need to be treated to remove hydrocarbons and other material before the water can be released. Dewatering wells may inhibit the ability to raise pressure within a treatment area to a desired value since dewatering wells are constantly removing fluid from the formation.

Water presence in a low temperature zone may allow for the formation of a frozen barrier. The frozen barrier may be a monolithic, impermeable structure. After the frozen barrier is established, the energy requirements needed to maintain the frozen barrier may be significantly reduced, as compared to the energy costs needed to establish the frozen barrier. In some embodiments, the reduction in cost may be a factor of 10 or more. In other embodiments, the reduction in cost may be less dramatic, such as a reduction by a factor of about 3 or 4.

In many formations, hydrocarbon containing portions of the formation are saturated or contain sufficient amounts of formation water to allow for formation of a frozen barrier. In some formations, water may be added to the formation adjacent to freeze wells after and/or during formation of a low temperature zone so that a frozen barrier will be formed.

In some in situ conversion embodiments, a low temperature zone may be formed around a treatment area. During heating of the treatment area, water may be released from the treatment area as steam and/or entrained water in formation fluids. In general, when a treatment area is initially heated, water present in the formation is mobilized before substantial quantities of hydrocarbons are produced. The water may be free water and/or released water that was attached or bound to clays or minerals ("bound water"). Mobilized water may flow into the low temperature zone. The water may condense and subsequently solidify in the low temperature zone to form a frozen barrier.

Pyrolyzing hydrocarbons and/or oxidizing hydrocarbons may form water vapor during in situ conversion. A significant portion of the generated water vapor may be removed from the formation through production wells. A small portion of the generated water vapor may migrate towards the perimeter of the treatment area. As the water approaches the low temperature zone formed by the freeze wells, a portion of the water may condense to liquid water in the low temperature zone. If the low temperature zone is cold enough, or if the liquid water moves into a cold enough portion of the low temperature zone, the water may solidify.

In some embodiments, freeze wells may form a low temperature zone that does not result in solidification of formation fluid. For example, if there is insufficient water or other fluid with a relatively high freezing point in the formation around the freeze wells, then the freeze wells may not form a frozen barrier. Instead, a low temperature zone may be formed. During an in situ conversion process, formation fluid may migrate into the low temperature zone. A portion of formation fluid (e.g., low freezing point hydrocarbons) may condense in the low temperature zone. The condensed fluid may fill pore space within the low temperature zone. The condensed fluid may form a barrier to additional fluid flow into or out of the low temperature zone. A portion of the formation fluid (e.g., water vapor) may condense and freeze within the low temperature zone to form a frozen barrier. Condensed formation fluid and/or solidified formation fluid may form a barrier to further fluid flow into or out of the low temperature zone.

Freeze wells may be initiated a significant time in advance of initiation of heat sources that will heat a treatment area. Initiating freeze wells in advance of heat source initiation may allow for the formation of a thick interconnected frozen perimeter barrier before formation temperature in a treatment area is raised. In some embodiments, heat sources that are located a large distance away from a perimeter of a treatment area may be initiated before, simultaneously with, or shortly after initiation of freeze wells.

Heat sources may not be able to break through a frozen perimeter barrier during thermal treatment of a treatment area. In some embodiments, a frozen perimeter barrier may continue to expand for a significant time after heating is initiated. Thermal diffusivity of a hot, dry formation may be significantly smaller than thermal diffusivity of a frozen formation. The difference in thermal diffusivities between hot, dry formation and frozen formation implies that a cold zone will expand at a faster rate than a hot zone. Even if heat sources are placed relatively close to freeze wells that have formed a frozen barrier (e.g., about 1 m away from freeze wells that have established a frozen barrier), the heat sources will typically not be able to break through the frozen barrier if coolant is supplied to the freeze wells. In certain in situ conversion process embodiments, freeze wells are positioned a significant distance away from the heat sources and other ICP wells. The distance may be about 3 m, 5 m, 10 m, 15 m, or greater. The frozen barrier formed by the freeze wells may expand on an outward side of the perimeter barrier even when heat sources heat the formation on an inward side of the perimeter barrier.

Fluid in low temperature zones 108 with a freezing point above a temperature of the low temperature zones may solidify in the low temperature zones to form perimeter barrier 102, as depicted in FIG. 1. Typically, the fluid that solidifies to form perimeter barrier 102 will be a portion of formation water. Two or more rows of freeze wells may be installed around treatment area 100 to form a thicker low temperature zone 108 than can be formed using a single row of freeze wells. FIG. 7 depicts two rows of freeze wells 106 around treatment area 100. Freeze wells 106 may be placed around all of treatment area 100, or freeze wells may be placed around a portion of the treatment area. In some embodiments, natural fluid flow barriers (such as unfractured, substantially impermeable formation material) and/or artificial barriers (e.g., grout walls or interconnected sheet barriers) surround remaining portions of the treatment area when freeze wells do not surround all of the treatment area.

If more than one row of freeze wells surrounds a treatment area, the wells in a first row may be staggered relative to wells in a second row. In the freeze well arrangement embodiment depicted in FIG. 7, first separation distance 126 exists between freeze wells 106 in a row of freeze wells. Second separation distance 128 exists between freeze wells 106 in a first row and a second row. Second separation distance 128 may be about 10-75% (e.g., 30-60% or 50%) of first separation distance 126. Other separation distances and freeze well patterns may also be used.

FIG. 4 depicts an embodiment of an ICP system with freeze wells 106 that form low temperature zone 108 below a portion of a formation, a low temperature zone above a portion of a formation, and a low temperature zone along a perimeter of a portion of the formation. Portions of heat sources 116 and portions of production wells 118 may pass through low temperature zone 108 formed by freeze wells 106. The portions of heat sources 116 and production wells 118 that pass through low temperature zone 108 may be insulated to inhibit heat transfer to the low temperature zone. The insulation may include, but is not limited to, foamed cement, an air gap between an insulated liner placed in the production well, or a combination thereof.

Freeze wells may be placed in the formation so that there is minimal deviation in orientation of one freeze well relative to an adjacent freeze well. Excessive deviation may create a large separation distance between adjacent freeze wells that may not permit formation of an interconnected low temperature zone between the adjacent freeze wells. Factors that may influence the manner in which freeze wells are inserted into the ground include, but are not limited to, freeze well insertion time, depth that the freeze wells are to be inserted, formation properties, desired well orientation, and economics. Relatively low depth freeze wells may be impacted and/or vibrationally inserted into some formations. Freeze wells may be impacted and/or vibrationally inserted into formations to depths from about 1 m to about 100 m without excessive deviation in orientation of freeze wells relative to adjacent freeze wells in some types of formations. Freeze wells placed deep in a formation or in formations with layers that are difficult to drill through may be placed in the formation by directional drilling and/or geosteering. Electrical, magnetic, and/or other signals produced in an adjacent freeze well may also be used to guide directionally drilled wells so that a desired spacing between adjacent wells is maintained. Relatively tight control of the spacing between freeze wells is an important factor in minimizing the time for completion of a low temperature zone.

FIG. 8 depicts a representation of an embodiment of freeze well 106 that is directionally drilled into a formation. Freeze well 106 may enter the formation at a first location and exit the formation at a second location so that both ends of the freeze well are above the ground surface. Refrigerant flow through freeze well 106 may reduce the temperature of the formation adjacent to the freeze well to form low temperature zone 108. Refrigerant passing through freeze well 106 may be passed through an adjacent freeze well or freeze wells. Temperature of the refrigerant may be monitored. When the refrigerant temperature exceeds a desired value, the refrigerant may be directed to a refrigeration unit or units to reduce the temperature of the refrigerant before recycling the refrigerant back into the freeze wells. The use of freeze wells that both enter and exit the formation may eliminate the need to accommodate an inlet refrigerant passage and an outlet refrigerant passage in each freeze well.

Freeze well 106 depicted in the embodiment of FIG. 8 forms part of frozen barrier 102 below water body 130. Water body 130 may be any type of water body such as a pond, lake, stream, or river. In some embodiments, the water body may be a subsurface water body such as an underground stream or river. Freeze well 106 is one of many freeze wells that may inhibit downward migration of water from water body 130 to hydrocarbon containing layer 110.

FIG. 9 depicts a representation of freeze wells 106 used to form a low temperature zone on a side of hydrocarbon containing layer 110. In some embodiments, freeze wells 106 may be placed in a non-hydrocarbon containing layer that is adjacent to hydrocarbon containing layer 110. In the depicted embodiment, freeze wells 106 are oriented along dip of hydrocarbon containing layer 110. In some embodiments, freeze wells may be inserted into the formation from two different directions or substantially perpendicular to the ground surface to limit the length of the freeze wells. Freeze well 106' and other freeze wells may be inserted into hydrocarbon containing layer 110 to form a perimeter barrier that inhibits fluid flow along the hydrocarbon containing layer. If needed, additional freeze wells may be installed to form perimeter barriers to inhibit fluid flow into or from overburden 112 or underburden 114.

In some embodiments, dewatering wells 120 may extend into formation 110 as depicted in FIG. 3. Dewatering wells 120 may be used to remove formation water from hydrocarbon containing layer 110 after freeze wells 106 form perimeter barrier 102. Water may flow through hydrocarbon containing layer 110 in an existing fracture system and channels. Only a small number of dewatering wells 120 may be needed to dewater treatment area 100 because the formation may have a large permeability due to the existing fracture system and channels. Dewatering wells 120 may be placed relatively close to freeze wells 106. In some embodiments, dewatering wells may be temporarily sealed after dewatering. If dewatering wells are placed close to freeze wells or to a low temperature zone formed by freeze wells, the dewatering wells may be filled with water. Expanding low temperature zone 108 may freeze the water placed in the dewatering wells to seal the dewatering wells. Dewatering wells 120 may be re-opened after completion of in situ conversion. After in situ conversion, dewatering wells 120 may be used during clean up procedures for injection or removal of fluids.

In some embodiments, selected production wells, heat sources, or other types of ICP wells may be temporarily converted to dewatering wells by attaching pumps to the selected wells. The converted wells may supplement dewatering wells or eliminate the need for separate dewatering wells. Converting other wells to dewatering wells may eliminate costs associated with drilling wellbores for dewatering wells.

FIG. 10 depicts a representation of an embodiment of a well system for treating a formation. Hydrocarbon containing layer 110 may include leached/fractured portion 132 and non-leached/non-fractured portion 134. Formation water may flow through leached/fractured portion 132. Non-leached/non-fractured portion 134 may be unsaturated and relatively dry. In some formations, leached/fractured portion 132 may be beneath 100 m or more of overburden 112, and the leached/fractured portion may extend 200 m or more into the formation. Non-leached/non-fractured portion 134 may extend 400 m or more deeper into the formation.

Heat sources 116 may extend to underburden 114 below non-leached/non-fractured portion 134. Production wells may extend into the non-leached/non-fractured portion of the formation. The production wells may have perforations, or be open wellbores, along the portions extending into the leached/fractured portion and non-leached/non-fractured portions of the hydrocarbon containing layer. Freeze wells 106 may extend close to, or a short distance into, non-leached/non-fractured portion 134. Freeze wells 106 may be offset from heat sources 116 and production wells a distance sufficient to allow hydrocarbon material below the freeze wells to remain unpyrolyzed during treatment of the formation (e.g., about 30 m). Freeze wells 106 may inhibit formation water from flowing into hydrocarbon containing layer 110. Advantageously, freeze wells 106 do not need to extend along the full length of hydrocarbon material that is to be subjected to in situ conversion, because non-leached/non-fractured portion 134 beneath freeze wells 106 may remain untreated. If treatment of the formation generates thermal fractures in the non-leached/non-fractured portion 134 that propagate towards and/or past freeze wells 106, the fractures may remain substantially horizontally oriented. Horizontally oriented fractures will not intersect the leached/fractured portion 132 to allow formation water to enter into treatment area 100.

In some embodiments, refrigerant may be delivered to freeze well 106 through cold side conduit 140. Refrigerant may flow through freeze well 106 to warm side conduit 138. Cold side conduits 140 and warm side conduits 138 (as shown in FIG. 10) may be made of insulated polymer piping such as HDPE (high-density polyethylene). In some freeze well embodiments, freeze well 106 may include port 136. Temperature probes, such as resistance temperature devices, may be inserted into port 136.

Various types of refrigeration systems may be used to form a low temperature zone. Determination of an appropriate refrigeration system may be based on many factors, including, but not limited to: type of freeze well; a distance between adjacent freeze wells; refrigerant; time frame in which to form a low temperature zone; depth of the low temperature zone; temperature differential to which the refrigerant will be subjected; chemical and physical properties of the refrigerant; environmental concerns related to potential refrigerant releases, leaks, or spills; economics; formation water flow in the formation; composition and properties of formation water; and various properties of the formation such as thermal conductivity, thermal diffusivity, and heat capacity.

Several different types of freeze wells may be used to form a low temperature zone. The type of freeze well used may depend on the type of refrigeration system used to form a low temperature zone. The type of refrigeration system may be, but is not limited to, a batch operated refrigeration system, a circulated fluid refrigeration system, a refrigeration system that utilizes a vaporization cycle, a refrigeration system that utilizes an adsorption-desorption refrigeration cycle, or a refrigeration system that uses an absorption-desorption refrigeration cycle. Different types of refrigeration systems may be used at different times during formation and/or maintenance of a low temperature zone. In some embodiments, freeze wells may include casings. In some embodiments, freeze wells may include perforated casings or casings with other types of openings. In some embodiments, a portion of a freeze well may be an open wellbore.

Refrigeration systems may utilize a liquid refrigerant that is circulated through freeze wells. A liquid circulation system utilizes heat transfer between a circulated liquid and the formation without a significant portion of the refrigerant undergoing a phase change. The liquid may be any type of heat transfer fluid able to function at cold temperatures. Some of the desired properties for a liquid refrigerant are: a low working temperature, low viscosity, high specific heat capacity, high thermal conductivity, low corrosiveness, and low toxicity. A low working temperature of the refrigerant allows for formation of a large low temperature zone around a freeze well. A low working temperature of the liquid should be about -20 °C or lower. Fluids having low working temperatures at or below -20 °C may include certain salt solutions (e.g., solutions containing calcium chloride or lithium chloride). Other salt solutions may include salts of certain organic acids (e.g., potassium formate, potassium acetate, potassium citrate, ammonium formate, ammonium acetate, ammonium citrate, sodium citrate, sodium formate, sodium acetate). One liquid that may be used as a refrigerant below -50 °C is Freezium®, available from Kemira Chemicals (Helsinki, Finland). Another liquid refrigerant is a solution of ammonia and water with a weight percent of ammonia between about 20% and about 40%. .

To form a low temperature zone for in situ conversion processes for formations, the use of a refrigerant having an initial cold temperature of about -50 °C or lower may be desirable. Refrigerants having initial temperatures warmer than about -50 °C may also be used, but such refrigerants may require longer times for the low temperature zones produced by individual freeze wells to connect. In addition, such refrigerants may require the use of closer freeze well spacings and/or more freeze wells.

A refrigeration unit may be used to reduce the temperature of a refrigerant liquid to a low working temperature. In some embodiments, the refrigeration unit may utilize an ammonia vaporization cycle. Refrigeration units are available from Cool Man Inc. (Milwaukee, Wisconsin), Gartner Refrigeration & Manufacturing (Minneapolis, Minnesota), and other suppliers. In some embodiments, a cascading refrigeration system may be utilized with a first stage of ammonia and a second stage of carbon dioxide. The circulating refrigerant through the freeze wells may be 30 weight % ammonia in water (aqua ammonia).

A vaporization cycle refrigeration system may be used to form and/or maintain a low temperature zone. A liquid refrigerant may be introduced into a plurality of wells. The refrigerant may absorb heat from the formation and vaporize. The vaporized refrigerant may be circulated to a refrigeration unit that compresses the refrigerant to a liquid and reintroduces the refrigerant into the freeze wells. The refrigerant may be, but is not limited to, liquid nitrogen, ammonia, carbon dioxide, a low molecular weight hydrocarbon (e.g., propane, isobutane, cyclopentane) and/or mixtures of ammonia and water (e.g., about 30 % mixture of ammonia and water). After vaporization, the fluid may be recompressed to a liquid in a refrigeration unit or refrigeration units and circulated back into the freeze wells. The use of a circulated refrigerant system may allow economical formation and/or maintenance of a long low temperature zone that surrounds a large treatment area.

In certain embodiments, freeze well 106 may extend into hydrocarbon layer 110 as depicted in FIG. 11. One or more baffles 135 may be positioned in annular space 137 between freeze well 106 and hydrocarbon containing layer 110. Water may flow through hydrocarbon containing layer 110 through leached/fractured portion 132 into annulus 137 to overburden 112. Baffles 135 may inhibit or slow the flow of the water in annulus 137. Slowing the flow rate of water in annulus 137 may increase the rate of freezing of water in the annulus by increasing the contact time between the water and freeze well 106. Baffles 135 may include rubberized metal, plastic, etc. In some embodiments, baffles 135 may be cement catchers.

FIG. 12 depicts an embodiment of freeze well 106. Freeze well 106 may have first end 146 at a first location on the surface and second end 148 at a second location on the surface. Freeze well 106 may include first conduit 142 and second conduit 144. In certain embodiments, first conduit 142 and second conduit 144 may be concentric, or coaxial, conduits. In one embodiment, as shown in FIG. 12second conduit 144 is located coaxially within first conduit 142. First conduit 142 and second conduit 144 may be made from stainless steel or other suitable materials chemically resistant to refrigerant. In some embodiments, first conduit 142 and second conduit 144 may include insulated portions in overburden 112. Portions of first conduit 142 and/or portions of second conduit 144 that are adjacent to un-cooled portions of the formation may include an insulating material (e.g., high density polyethylene) and/or the conduit portions may be insulated with an insulating material. Portions of first conduit 142 and/or portions of second conduit 144 that are adjacent to cooled portions of the formation may be formed of a thermally conductive material (e.g., copper or a copper alloy). A thermally conductive material may enhance heat transfer between the formation and refrigerant in the conduit.

Refrigerant may be provided to first conduit 142 at second end 148 of freeze well 106. Refrigerant may be provided to second conduit 144 at first end 146 of freeze well 106. In an embodiment, refrigerant in first conduit 142 (which flows from second end 148 towards first end 146) may flow countercurrently to refrigerant in second conduit 144 (which flows from first end 146 towards second end 148). In some embodiments, refrigerant may flow co-currently through freeze well 106 (i.e., refrigerant is provided to first conduit 142 and second conduit 144 at the same end of the freeze well). Flowing refrigerant countercurrently in coaxial conduits may more uniformly cool hydrocarbon layer 110 and produce more uniform temperatures in the treatment area. In addition, a lower pressure in a refrigerant may be maintained by flowing the refrigerant through a conduit with openings at both ends of the conduit compare to flowing the refrigerant through a conduit with only one open end. Conduits with only one open end generally have a bend or return within the freeze well that may increase a pressure of the refrigerant.

In some embodiments, refrigerant exiting first conduit 142 and/or second conduit 144 may be recycled or reused in another freeze well or returned to the same freeze well. For example, refrigerant exiting first conduit 142 may be provided to second conduit 144. In certain embodiments, refrigerant may be compressed before being recycled or reused. In some embodiments, spacers may be positioned at selected locations along the length of first conduit 142 and second conduit 144 to inhibit the conduits from physically contacting each other.

Spacing between adjacent freeze wells may be a function of a number of different factors. The factors may include, but are not limited to, physical properties of formation material, type of refrigeration system, type of refrigerant, flow rate of material into or out of a treatment area defined by the freeze wells, time for forming the low temperature zone, and economic considerations. Consolidated or partially consolidated formation material may allow for a large separation distance between freeze wells. A separation distance between freeze wells in consolidated or partially consolidated formation material may be from about 3 m to 10 m or larger. In an embodiment, the spacing between adjacent freeze wells is about 5 m. Spacing between freeze wells in unconsolidated or substantially unconsolidated formation material may need to be smaller than spacing in consolidated formation material. A separation distance between freeze wells in unconsolidated material may be 1 m or more.

In an embodiment, freeze wells may be positioned between an inner row and an outer row of dewatering wells. The inner row of dewatering wells and the outer row of dewatering wells may be operated to have a minimal pressure differential so that fluid flow between the inner row of dewatering wells and the outer row of dewatering wells is minimized. The dewatering wells may remove formation water between the outer dewatering row and the inner dewatering row. The freeze wells may be initialized after removal of formation water by the dewatering wells. The freeze wells may cool the formation between the inner row and the outer row to form a low temperature zone. The power supplied to the dewatering wells may be reduced stepwise after the freeze wells form an interconnected low temperature zone that is able to solidify formation water. Reduction of power to the dewatering wells may allow some water to enter the low temperature zone. The water may freeze to form a frozen barrier. Operation of the dewatering wells may be ended when the frozen barrier is fully formed.

Freeze well placement may vary depending on a number of factors. The factors may include, but are not limited to, predominant direction of fluid flow within the formation; type of refrigeration system used; spacing of freeze wells; and characteristics of the formation such as depth, length, thickness, and dip. Placement of freeze wells may also vary across a formation to account for variations in geological strata. In some embodiments, freeze wells may be inserted into hydrocarbon containing portions of a formation. In some embodiments, freeze wells may be placed near hydrocarbon containing portions of a formation. In some embodiments, some freeze wells may be positioned in hydrocarbon containing portions while other freeze wells are placed proximate the hydrocarbon containing portions. Placement of heat sources, dewatering wells, and/oı production wells may also vary depending on the factors affecting freeze well placement.

A number of freeze wells needed to surround an area increases at a significantly lower rate than the number of ICP wells needed to thermally treat the surrounded area as the size of the surrounded area increases. This is because the surface-to-volume ratio decreases with the radius of a treated volume.

A test may be performed to determine or confirm formation of a frozen barrier. The test may be, but is not limited to, a pulse test, a pressure test, and/or a tracer chemical test.
If tests indicate that a frozen perimeter barrier has not been formed by the freeze wells, the location of incomplete sections of the perimeter barrier may be determined. Pulse tests may indicate the location of unformed portions of a perimeter barrier. Tracer tests may indicate the general direction in which there is an incomplete section of perimeter barrier.

A ground cover may be sealed to the ground, to ICP wells, to freeze wells, and to other equipment that passes through the ground cover. The ground cover may inhibit release of formation fluid to the atmosphere and/or inhibit rain and run-off water seepage into a treatment area from the ground surface. The choice of ground cover material may be based on temperatures and chemicals to which the ground cover is subjected. In embodiments in which an overburden is sufficiently thick so that temperatures at the ground surface are not influenced, or are only slightly elevated, by heating of the formation, the ground cover may be a polymer sheet. For thinner overburdens, where heating the formation may significantly influence the temperature at ground surface, the ground cover may be formed of metal sheet placed over the treatment area.

For some processes, a low temperature zone may be used to isolate a treatment area. A treatment area surrounded by a low temperature zone may be used, in certain embodiments, as a storage area for fluids produced or needed on site. Fluids may be diverted from other areas of the formation in the event of an emergency. Alternatively, fluids may be stored in a treatment area for later use. A low temperature zone may inhibit flow of stored fluids from a treatment area depending on characteristics of the stored fluids. A frozen barrier zone may be necessary to inhibit flow of certain stored fluids from a treatment area. Other processes which may benefit from an isolated treatment zone may include, but are not limited to, synthesis gas generation, upgrading of hydrocarbon containing feed streams, filtration of feed stocks, and/or solution mining.

In some in situ conversion process embodiments, three or more sets of wells may surround a treatment area. FIG. 13 depicts a well pattern embodiment for an in situ conversion process. Treatment area 100 may include a plurality of heat sources, production wells, and other types of ICP wells 104. Treatment area 100 may be surrounded by a first set of freeze wells 150. The first set of freeze wells 150 may establish a frozen barrier that inhibits migration of fluid out of treatment area 100 during the in situ conversion process.

The first set of freeze wells 150 may be surrounded by a set of monitor and/or injection wells 152. Monitor and/or injection wells 152 may be used during the in situ conversion process to monitor temperature and monitor for the presence of formation fluid (e.g., for water, steam, hydrocarbons, etc.). If hydrocarbons or steam are detected, a breach of the frozen barrier established by the first set of freeze wells 150 may be indicated. Measures may be taken to determine the location of the breach in the frozen barrier. After determining the location of the breach, measures may be taken to stop the breach. In an embodiment, an additional freeze well or freeze wells may be inserted into the formation between the first set of freeze wells 150 and the set of monitor and/or injection wells 152 to seal the breach.

The set of monitor and/or injection wells 152 may be surrounded by a second set of freeze wells 154. The second set of freeze wells 154 may form a frozen barrier that inhibits migration of fluid (e.g., water) from outside the second set of freeze wells into treatment area 100. The second set of freeze wells 154 may also form a barrier that inhibits migration of fluid past the second set of freeze wells should the frozen barrier formed by the first set of freeze wells 150 develop a breach. A frozen barrier formed by the second set of freeze wells 154 may stop migration of formation fluid and allow sufficient time for the breach in the frozen barrier formed by the first set of freeze wells 150 to be fixed. Should a breach form in the frozen barrier formed by the first set of freeze wells 150, the frozen barrier formed by the second set of freeze wells 154 may limit the area that formation fluid from the treatment area can flow into, and thus the area that needs to be cleaned after the in situ conversion process is complete.

If the set of monitor and/or injection wells 152 detect the presence of formation water, a breach of the second set of freeze wells 154 may be indicated. Measures may be taken to determine the location of the breach in the second set of freeze wells 154. After determining the location of the breach, measures may be taken to stop the breach. In an embodiment, an additional freeze well or freeze wells may be inserted into the formation between the second set of freeze wells 154 and the set of monitor and/or injection wells 152 to seal the breach.

In many embodiments, a breach in the frozen barrier formed by freeze wells 150 will not occur during an in situ conversion process. To clean the treatment area after completion of the in situ conversion processes, the first set of freeze wells 150 may be deactivated. Fluid may be introduced through monitor and/or injection wells 152 to raise the temperature of the frozen barrier and force fluid back towards treatment area 100. The fluid forced into treatment area 100 may be produced from production wells in the treatment area. If a breach of the frozen barrier formed by the first set of freeze wells 150 is detected during the in situ conversion process, monitor and/or injection wells 152 may be used to remediate the area between the first set of freeze wells 150 and the second set of freeze wells 154 before, or simultaneously with, deactivating the first set of freeze wells. The ability to maintain the frozen barrier formed by the second set of freeze wells 154 after in situ conversion of hydrocarbons in treatment area 100 is complete may allow for cleansing of the treatment area with little or no possibility of spreading contaminants beyond the second set of freeze wells 154.

The set of monitor and/or injection wells 152 may be positioned at a distance between the first set of freeze wells 150 and the second set of freeze wells 154 to inhibit the monitor and/or injection wells from becoming frozen. In some embodiments, some or all of the monitor and/or injection wells 152 may include a heat source or heat sources (e.g., an electric heater, circulated fluid line, etc.) sufficient to inhibit the monitor and/or injection wells from freezing due to the low temperature zones created by freeze wells 150 and freeze wells 154.

In some in situ conversion process embodiments, a treatment area may be treated sequentially. An example of sequentially treating a treatment area with different processes includes installing a plurality of freeze wells within a formation around a treatment area. Pumping wells are placed proximate the freeze wells within the treatment area. After a low temperature zone is formed, the pumping wells are engaged to reduce water content in the treatment area. After the pumping wells have reduced the water content, the low temperature zone expands to encompass some of the pumping wells. Heat is applied to the treatment area using heat sources. A mixture is produced from the formation. After a majority of the hydrocarbons recoverable by pyrolysis are recovered from the formation, synthesis gas generation is initiated. Following synthesis gas generation, the treatment area is used as a storage unit for fluids diverted from other treatment areas within the formation. The diverted fluids are produced from the treatment area. Before the low temperature zone is allowed to thaw, the treatment area is remediated. A first portion of a low temperature zone surrounding the pumping wells is allowed to thaw, exposing an unaltered portion of the formation. Water is provided to a second portion of a low temperature zone to form a frozen barrier zone. A drive fluid is provided to the treatment area through the pumping wells. The drive fluid may move some fluids remaining in the formation towards wells through which the fluids are produced. This movement may be the result of steam distillation of organic compounds, leaching of inorganic compounds into the drive fluid solution, and/or the force of the drive fluid "pushing" fluids from the pores. Drive fluid is injected into the treatment area until the removed drive fluid contains concentrations of the remaining fluids that fall below acceptable levels. After remediation of a treatment area, carbon dioxide is injected into the treatment area for sequestration.

In other embodiments, adjacent treatment areas may be undergoing different processes concurrently within separate low temperature zones. These differing processes may have varied requirements, for example, temperature and/or required constituents, which may be added to the section. In an embodiment, a low temperature zone may be sufficient to isolate a first treatment area from a second treatment area. An example of differing conditions required by two processes includes a first treatment area undergoing production of hydrocarbons at an average temperature of about 310 °C. A second treatment area adjacent to the first may undergo sequestration, a process, which depending on the component being sequestered, may be optimized at a temperature less than about 100 °C.

Providing a barrier to both mass and heat transfer may be necessary in some embodiments. A frozen barrier zone may be utilized to isolate a treatment area from the surrounding formation both thermally and hydraulically. For example, a first treatment area undergoing pyrolysis should be isolated both thermally and hydraulically from a second treatment area in which fluids are being stored.

As depicted in FIG. 14 and FIG. 15, dewatering wells 120 may surround treatment area 100. Dewatering wells 120 that surround treatment area 100 may be used to provide a barrier to fluid flow into the treatment area or migration of fluid out of the treatment area into surrounding formation. In an embodiment, a single ring of dewatering wells 120 surrounds treatment area 100. In other embodiments, two or more rings of dewatering wells surround a treatment area. In some embodiments that use multiple rings of dewatering wells 120, a pressure differential between adjacent dewatering well rings may be minimized to inhibit fluid flow between the rings of dewatering wells. During processing of treatment area 100, formation water removed by dewatering wells 120 in outer rings of wells may be substantially the same as formation water in areas of the formation not subjected to in situ conversion. Such water may be released with no treatment or minimal treatment. If removed water needs treatment before being released, the water may be passed through carbon beds or otherwise treated before being released. Water removed by dewatering wells 120 in inner rings of wells may contain some hydrocarbons. Water with significant amounts of hydrocarbon may be used for synthesis gas generation. In some embodiments, water with significant amounts of hydrocarbons may be passed through a portion of formation that has been subjected to in situ conversion. Remaining carbon within the portion of the formation may purify the water by adsorbing the hydrocarbons from the water.

In some embodiments, an outer ring of wells may be used to provide a fluid to the formation. In some embodiments, the provided fluids may entrain some formation fluids (e.g., vapors). An inner ring of dewatering wells may be used to recover the provided fluids and inhibit the migration of vapors. Recovered fluids may be separated into fluids to be recycled into the formation and formation fluids. Recycled fluids may then be provided to the formation. In some embodiments, a pressure gradient within a portion of the formation may increase recovery of the provided fluids.

Alternatively, an inner ring of wells may be used for dewatering while an outer ring is used to reduce an inflow of groundwater. In certain embodiments, an inner ring of wells is used to dewater the formation and fluid is pumped into the outer ring to confine vapors to the inner area.

Water within treatment area 100 may be pumped out of the treatment area prior to or during heating of the formation to pyrolysis temperatures. Removing water prior to or during heating may limit the water that needs to be vaporized by heat sources so that the heat sources are able to raise formation temperatures to pyrolysis temperatures more efficiently.

In some embodiments, well spacing between dewatering wells 120 may be arranged in convenient multiples of heater and/or production well spacing. Some dewatering wells may be converted to heater wells and/or production wells during in situ processing of a hydrocarbon containing formation. Spacing between dewatering wells may depend on a number of factors, including the hydrology of the formation. In some embodiments, spacing between dewatering wells may be 2 m, 5 m, 10 m, 20 m, or greater.

A spacing between dewatering wells and ICP wells, such as heat sources or production wells, may need to be large. The spacing may need to be large so that the dewatering wells and the in situ process wells are not significantly influenced by each other. In an embodiment, a spacing between dewatering wells and in situ process wells may need to be 30 m or more. Greater or lesser spacings may be used depending on formation properties. Also, a spacing between a property line and dewatering wells may need to be large so that dewatering does not influence water levels on adjacent property.

Further modifications and alternative embodiments of various aspects of the invention may be apparent to those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as described in the following claims. In addition, it is to be understood that features described herein independently may, in certain embodiments, be combined.

CLAIMS

1. A method of treating a hydrocarbon containing formation comprising:

inhibiting migration of fluids into a first treatment area of the formation from a surrounding portion of the formation;

heating a portion of the first treatment area with heaters to raise a temperature in the first treatment area above a pyrolysis temperature;

controlling heat input from the heaters into the portion to establish a substantially uniform permeability in the portion;

producing a mixture from the formation; and

controlling a pressure in the first treatment area of the formation to control a composition of the mixture produced from the formation.

2. The method of claim 1, wherein the surrounding portion of the formation comprises at least a portion beside, above, or below the first treatment area of the formation.

3. The method of any one of claims 1 or 2, wherein inhibiting migration of fluids into the first treatment area of the formation and the surrounding portion of the formation comprises providing a barrier to at least the portion of the formation and/or establishing a barrier in at least the portion of the formation.

4. The method of any one of claims 1-3, further comprising controlling a temperature, a heating rate, and/or an amount of fluid removed from the first treatment area.

5. The method of any one of claims 1-4, further comprising establishing a low temperature barrier zone proximate to the first treatment area of the formation.

6. The method of any one of claims 1-5, further comprising establishing a frozen barrier zone to inhibit migration of fluids into or out of the first treatment area.

7. The method of claim 6, wherein the frozen barrier zone is proximate to the first treatment area of the formation.

8. The method of any one of claims 6 or 7, wherein at least one or more heaters is

positioned greater than about 5 m from the frozen barrier zone.

9. The method of any one of claims 6-8, wherein at least one of one or more heaters is positioned less than about 1.5 m from the frozen barrier zone.

10. The method of any one of claims 6-8, further comprising thawing at least a portion of the frozen barrier zone; and wherein material in the thawed barrier zone area is substantially unaltered by the application of heat.

11. The method of any one of claims 6-10, further comprising providing water to the frozen barrier zone.

12. The method of any one of claims 6-11, further comprising:
positioning one or more monitoring wells outside the frozen barrier zone;
providing a tracer to the first treatment area; and
monitoring for movement of the tracer at the one or more monitoring wells.

13. The method of any one of claims 6-12, further comprising:
positioning one or more monitoring wells outside the frozen barrier zone;
providing an acoustic pulse to the first treatment area; and
monitoring for the acoustic pulse at the one or more monitoring wells.

14. The method of any one of claims 6-13, further comprising controlling compositions of fluids produced from the formation by controlling the fluid pressure in an area at least partially bounded by the frozen barrier zone.

15. The method of any one of claims 2-14, wherein at least a section of the barrier comprises one or more sulfur wells.

16. The method of any one of claims 2-15, wherein at least a section of the barrier comprises one or more dewatering wells.

17. The method of any one of claims 2-16, wherein at least a section of the barrier comprises one or more injection wells and one or more dewatering wells.

AMENDED SHEET

18. The method of any one of claims 1-17, further comprising pyrolyzing at least a portion of hydrocarbon containing material and/or generating synthesis gas in at least a portion of the first treatment area.

19. The method of any one of claims 2-18, wherein providing the barrier comprises:
providing a circulating fluid to the portion of the formation surrounding the first treatment area; and
removing the circulating fluid proximate to the first treatment area.

20. The method of any one of claims 1-19, further comprising inhibiting a release of formation fluid to the earth's atmosphere and/or inhibiting fluid seepage from a surface of the earth into the first treatment area.

21. The method of any one of claims 2-20, wherein at least a section of the barrier comprises a naturally occurring portion, an installed portion, an impermeable portion of the formation, and/or a self-sealing portion.

22. The method of any one of claims 2-21, wherein at least a portion of the barrier comprises a low temperature zone, and further comprising lowering a temperature in the low temperature zone to a temperature less than about a freezing temperature of water.

23. The method of any one of claims 2-22, wherein at least a portion of the barrier comprises a low temperature zone, and further comprising thawing at least a portion of the low temperature zone, wherein material in the thawed portion is substantially unaltered by the application of heat such that the structural integrity of the hydrocarbon containing formation is substantially maintained.

24. The method of any one of claims 1-23, further comprising:
treating the first treatment area using a first treatment process; and
treating a second treatment area using a second treatment process.

25. The method of any one of claims 1-24, further comprising thermally isolating the first treatment area from the surrounding portion of the formation.

AMENDED SHEET

26. The method of any one of claims 1-25, further comprising removing liquid water from at least a portion of the first treatment area.

27. The method of any one of claims 1-26, wherein the first treatment area is below a water table of the formation.

28. The method of any one of claims 1-27, further comprising providing a refrigerant to a plurality of freeze wells placed in a portion of the formation.

29. The method of any one of claims 27-28, further comprising:
cooling at least a portion of the refrigerant in an absorption refrigeration unit; and
providing a thermal energy source to the absorption refrigeration unit.

30. The method of claim 29, wherein the thermal energy source comprises water, steam, exhaust gas, and/or at least a portion of the produced fluids.

31. The method of any one of claims 29-30, wherein at least one of the plurality of freeze wells is located along strike or dip of a hydrocarbon containing portion of the formation.

32. The method of any one of claims 29-31, wherein the refrigerant has a freezing point of less than about -60 °C.

33. The method of any one of claims 29-32, wherein the refrigerant is provided at a temperature of less than about -50 °C.

34. The method of any one of claims 1-33, further comprising producing synthesis gas from at least a portion of the formation.

35. The method of any one of claims 1-34, further comprising removing fluid from the formation and controlling an amount of fluid removed from the formation.

36. The method of any one of claims 1-35, further comprising providing a grout wall to the part of the formation.

37. The method of any one of claims 1-36, further comprising inhibiting flow of water into or out of at least a portion of a treatment area.

38. The method of any one of claims 1-37, wherein the first treatment area is surrounded, in whole or in part, by one or more openings, and wherein at least one of the openings comprises a first end that contacts a ground surface at a first location, and a second opening that contacts the ground surface at a second location.

39. The method of claim 38, wherein one of the one or more openings comprises a first conduit positioned in a second conduit.

40. The method of any one of claims 38-39, wherein at least one opening comprises a first conduit positioned in a second conduit, the method further comprising flowing a refrigerant through the first conduit from the first end of the at least one opening towards a second end of the at least one opening and flowing an additional refrigerant through the second conduit from the second end of the at least one opening towards the first end of the at least one opening.

41. The method of claim 40, wherein the refrigerant flowing through the first conduit flows countercurrently or co-currently to the additional refrigerant flowing through the second conduit.

42. The method of any one of claims 38-41, further comprising forming at least one opening in the formation with a river crossing rig.

AMENDED SHEET

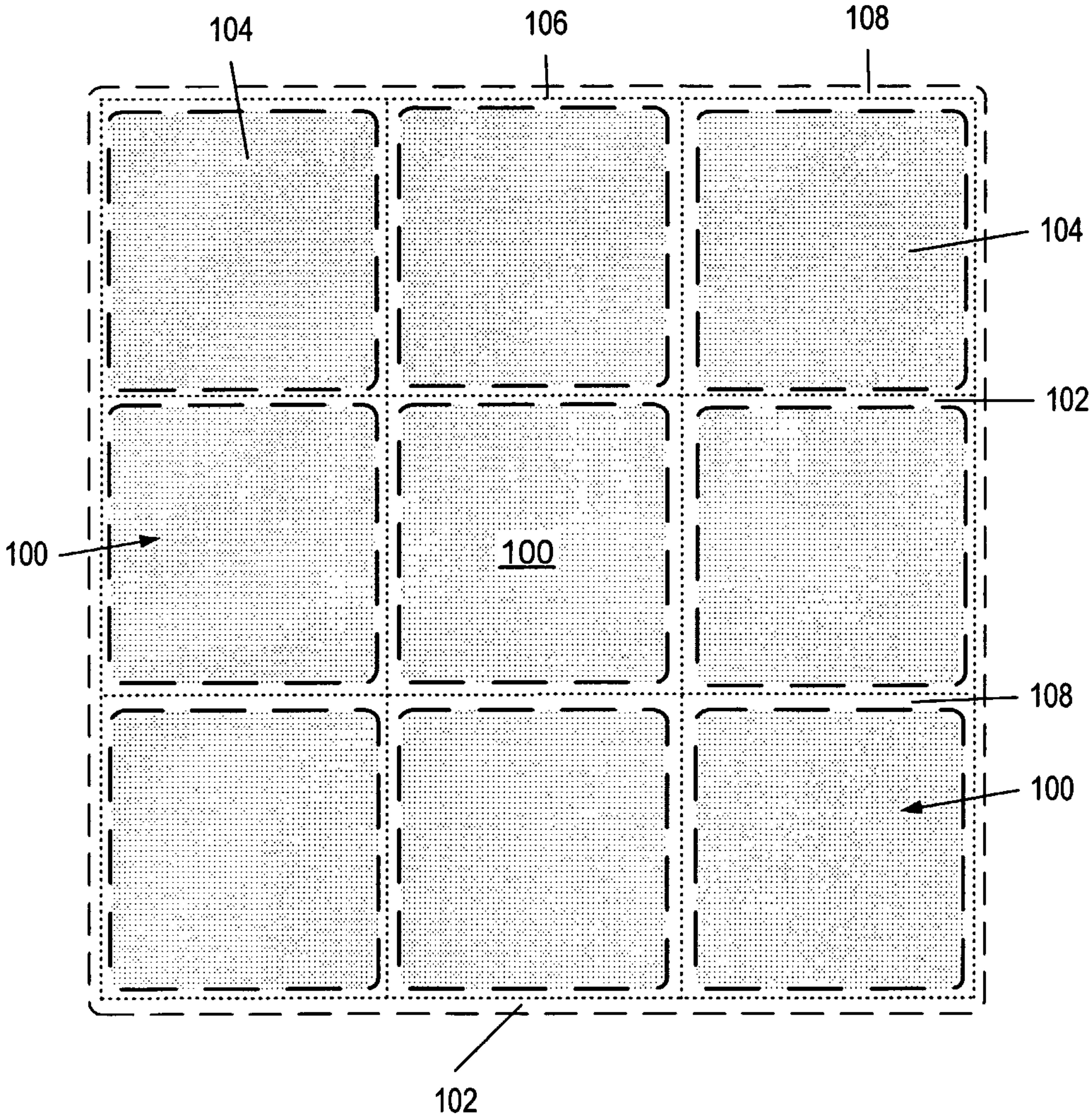


FIG. 1

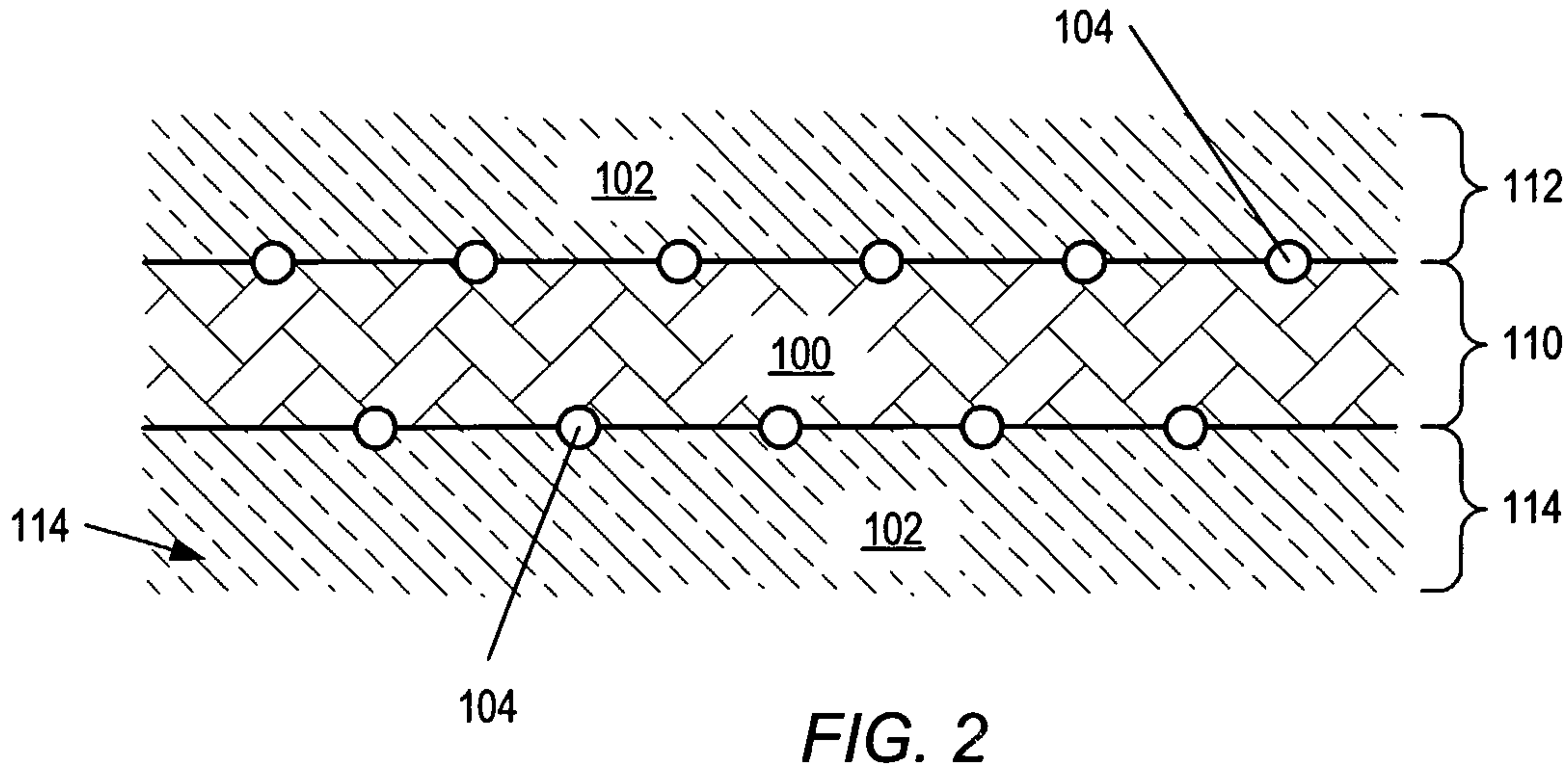
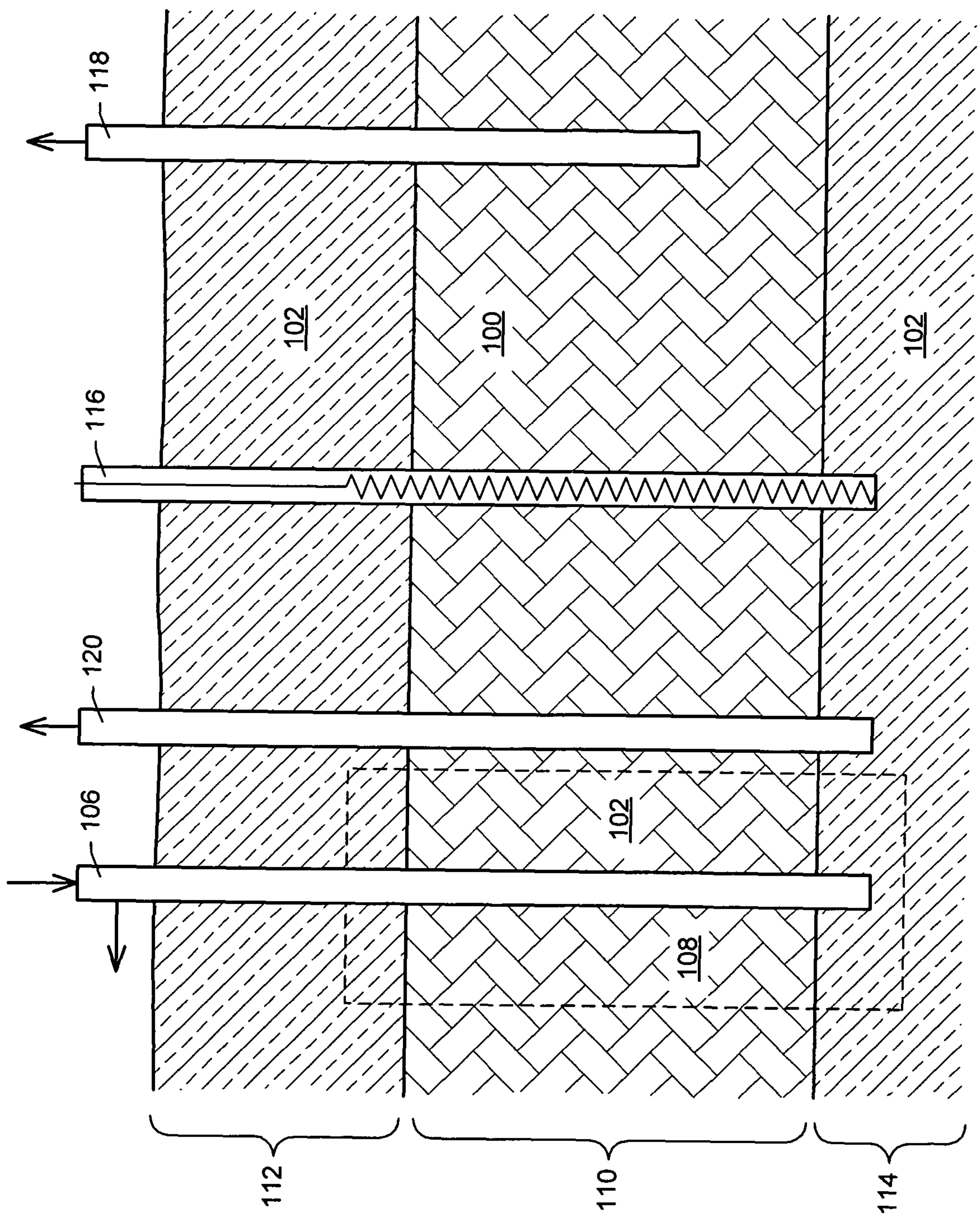


FIG. 2

FIG. 3



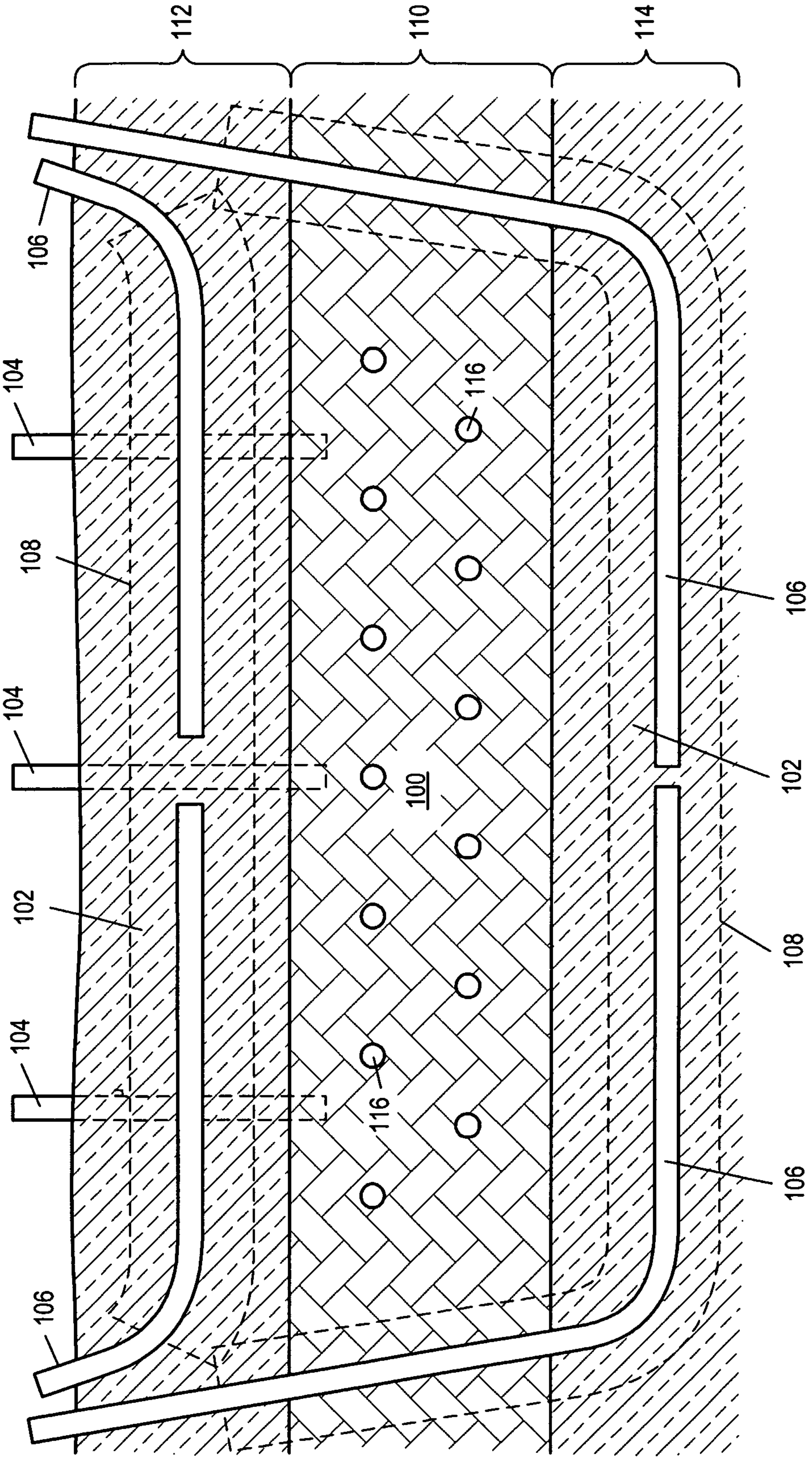

112
110
114
106
104
108
104
102
104
106
116
100
116
106
102
108
106

FIG. 4

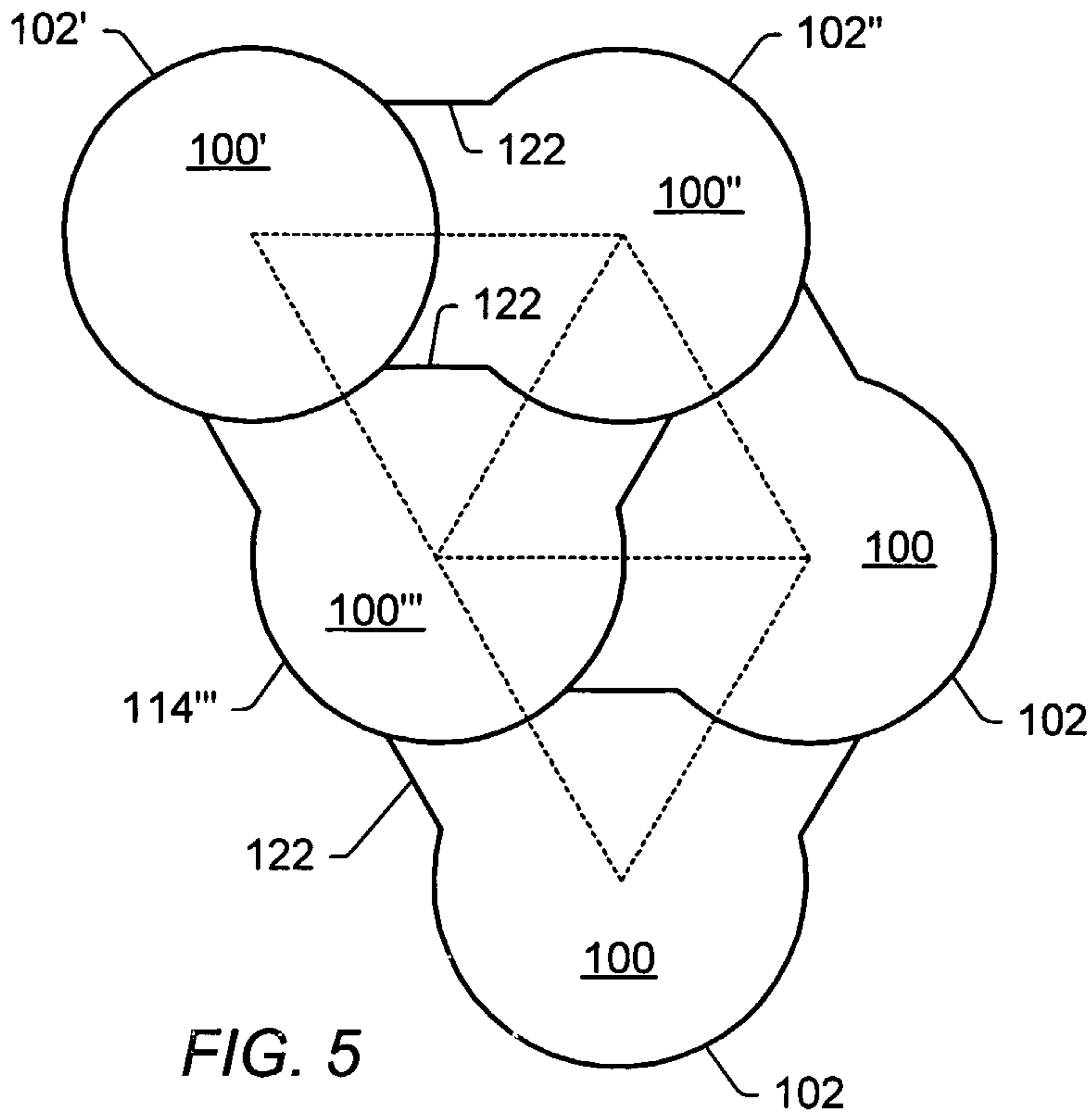


FIG. 5

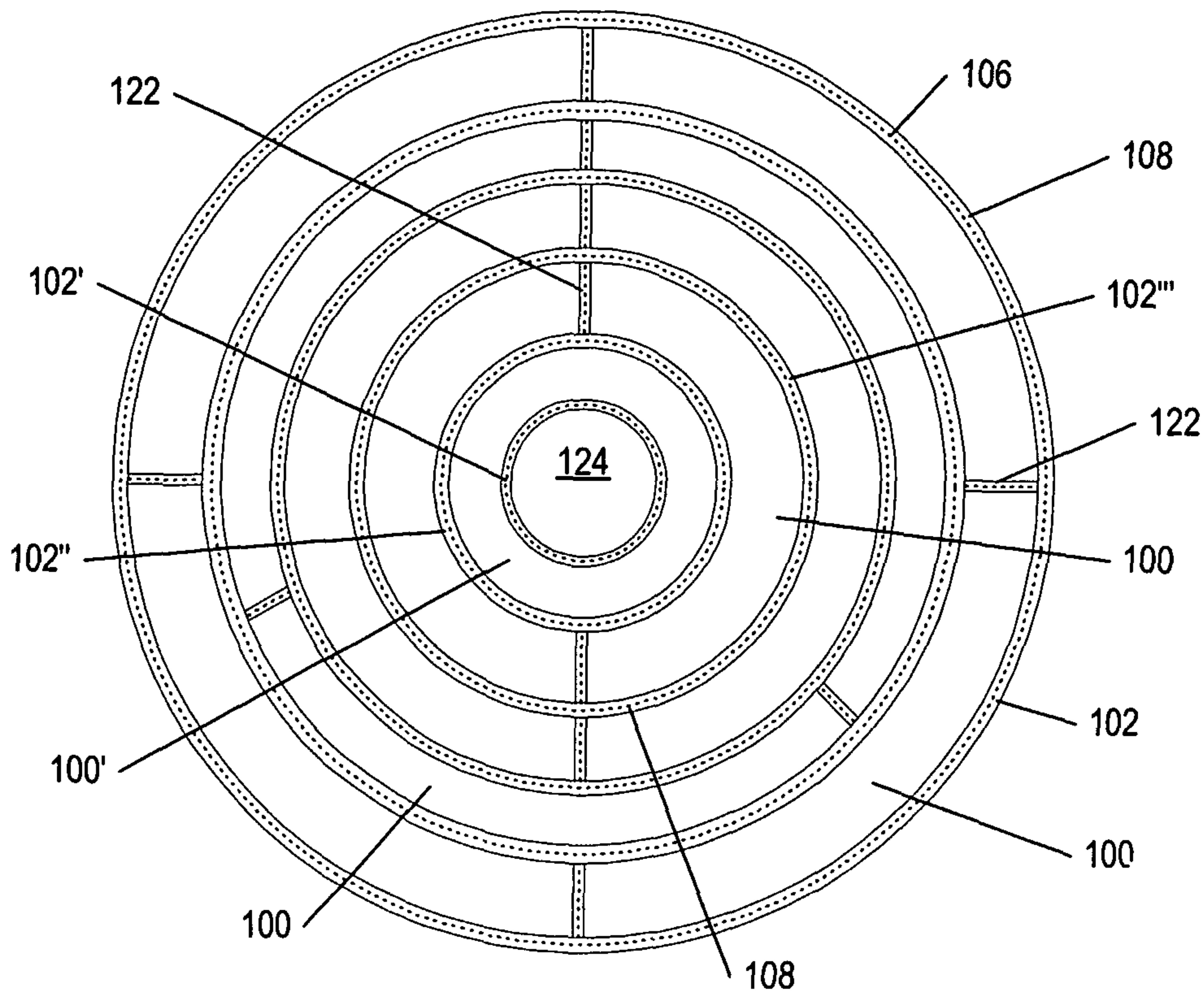

122
106
108
102'
102'''
122
124
102''
100
100'
102
100
100
108

FIG. 6

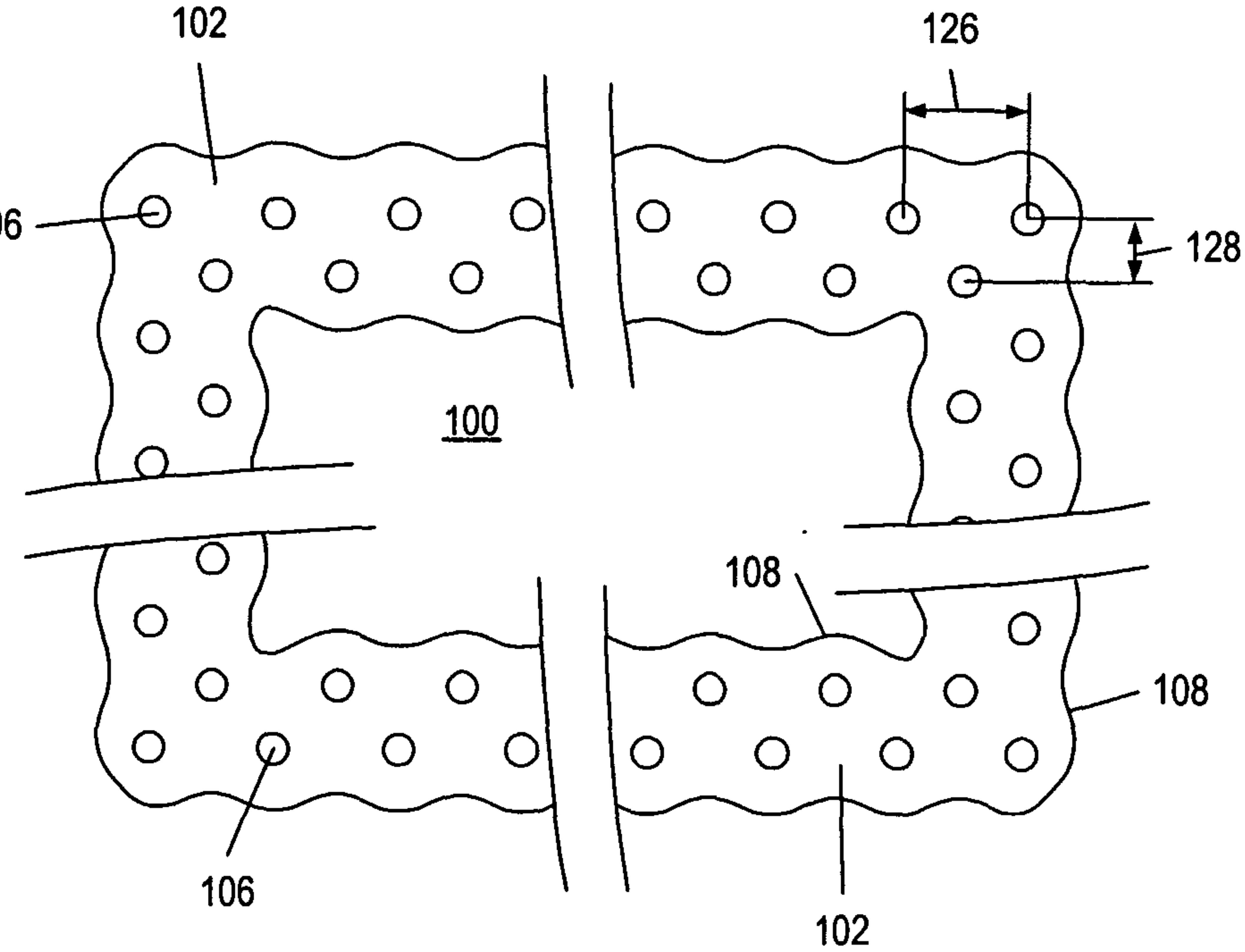

102
126
106
128
100
108
108
106
102

FIG. 7

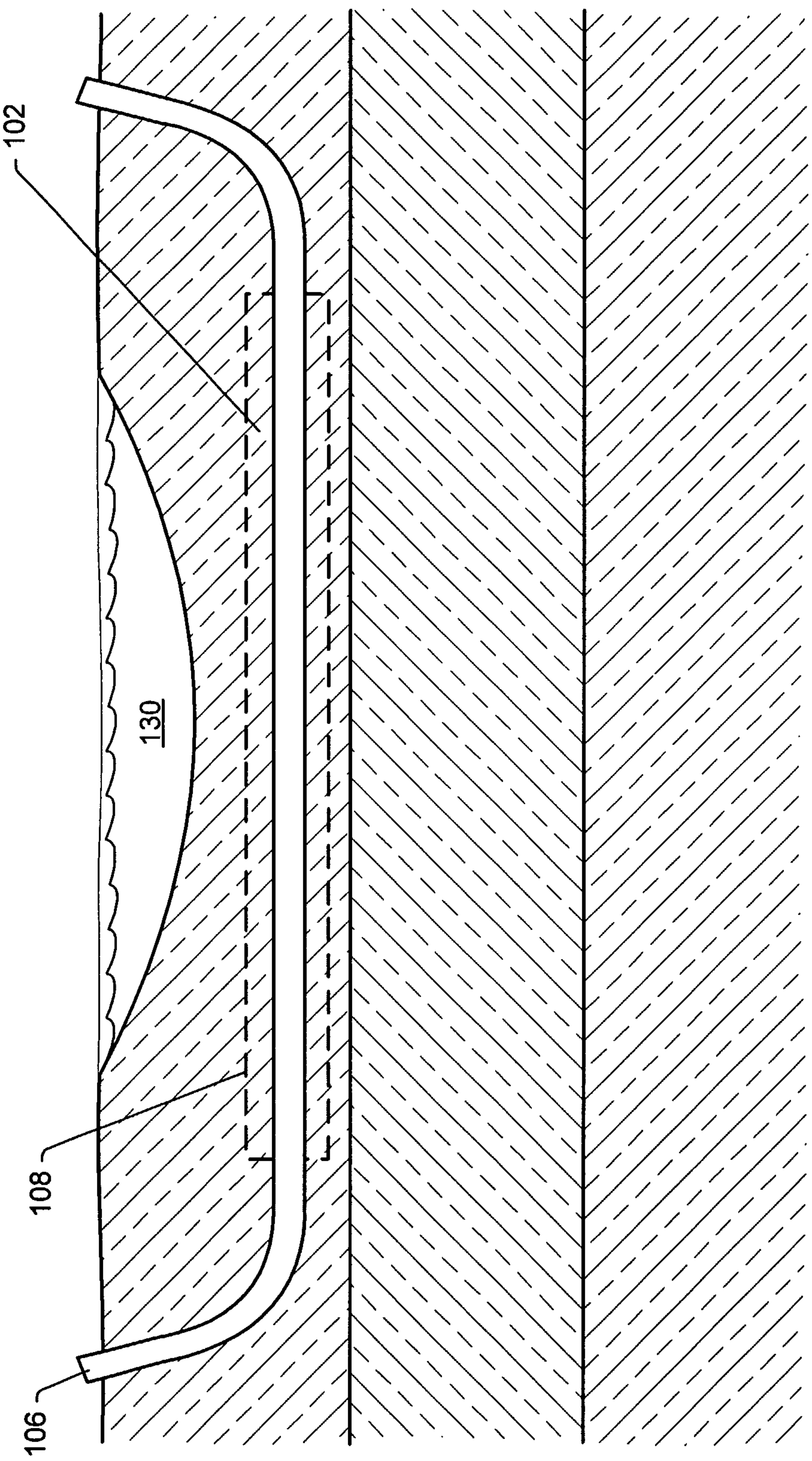


FIG. 8

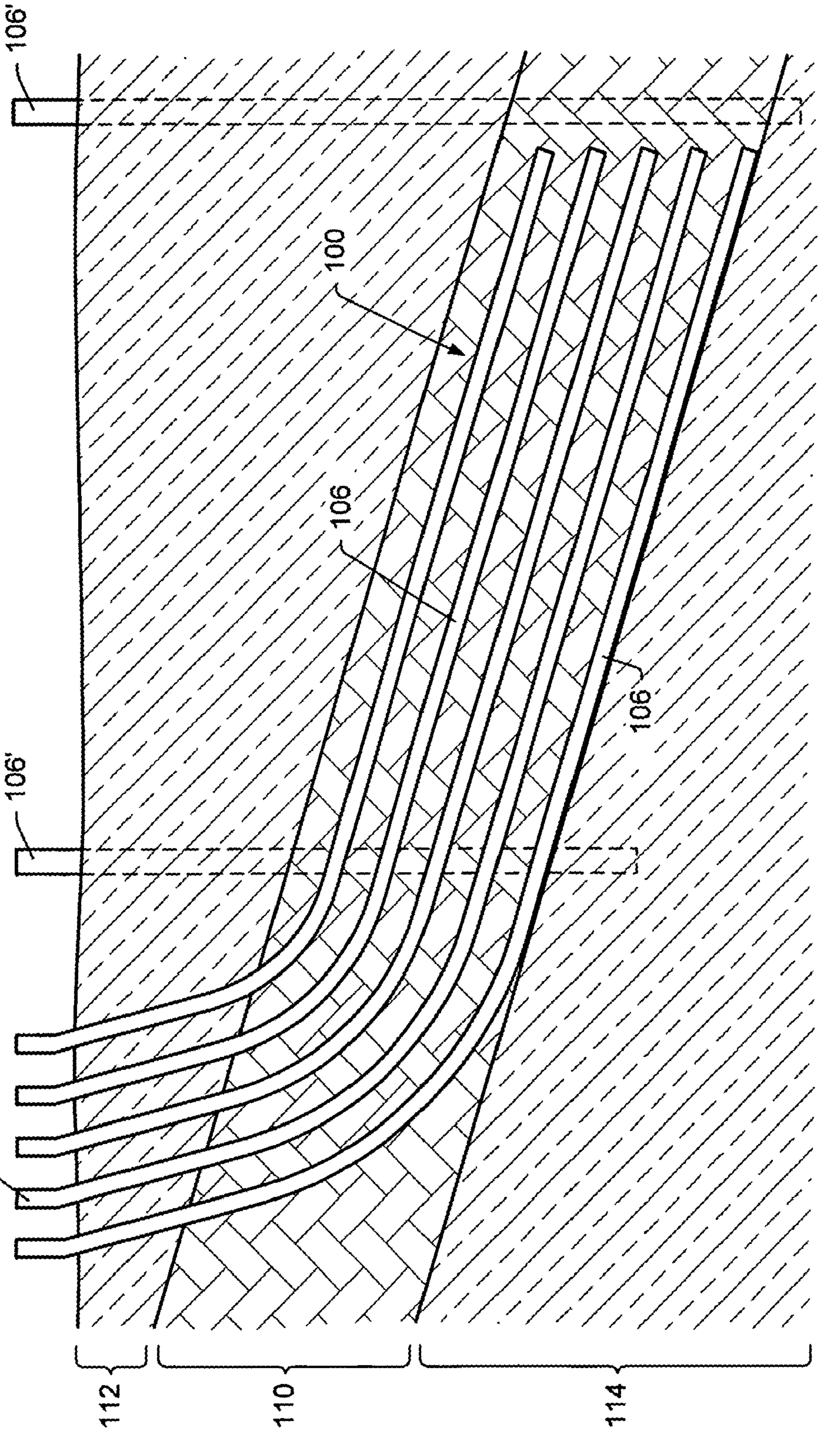


FIG. 9

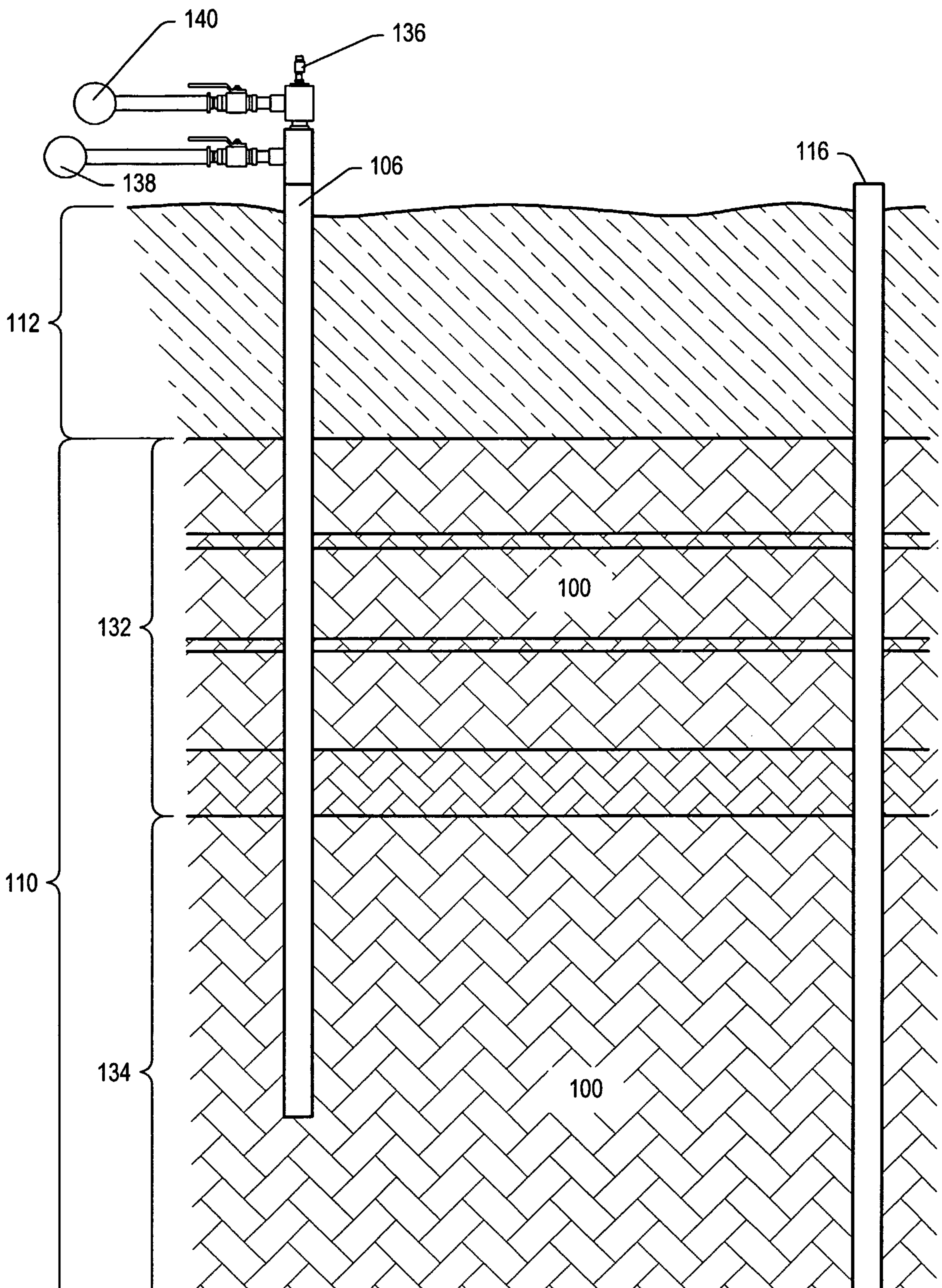


FIG. 10

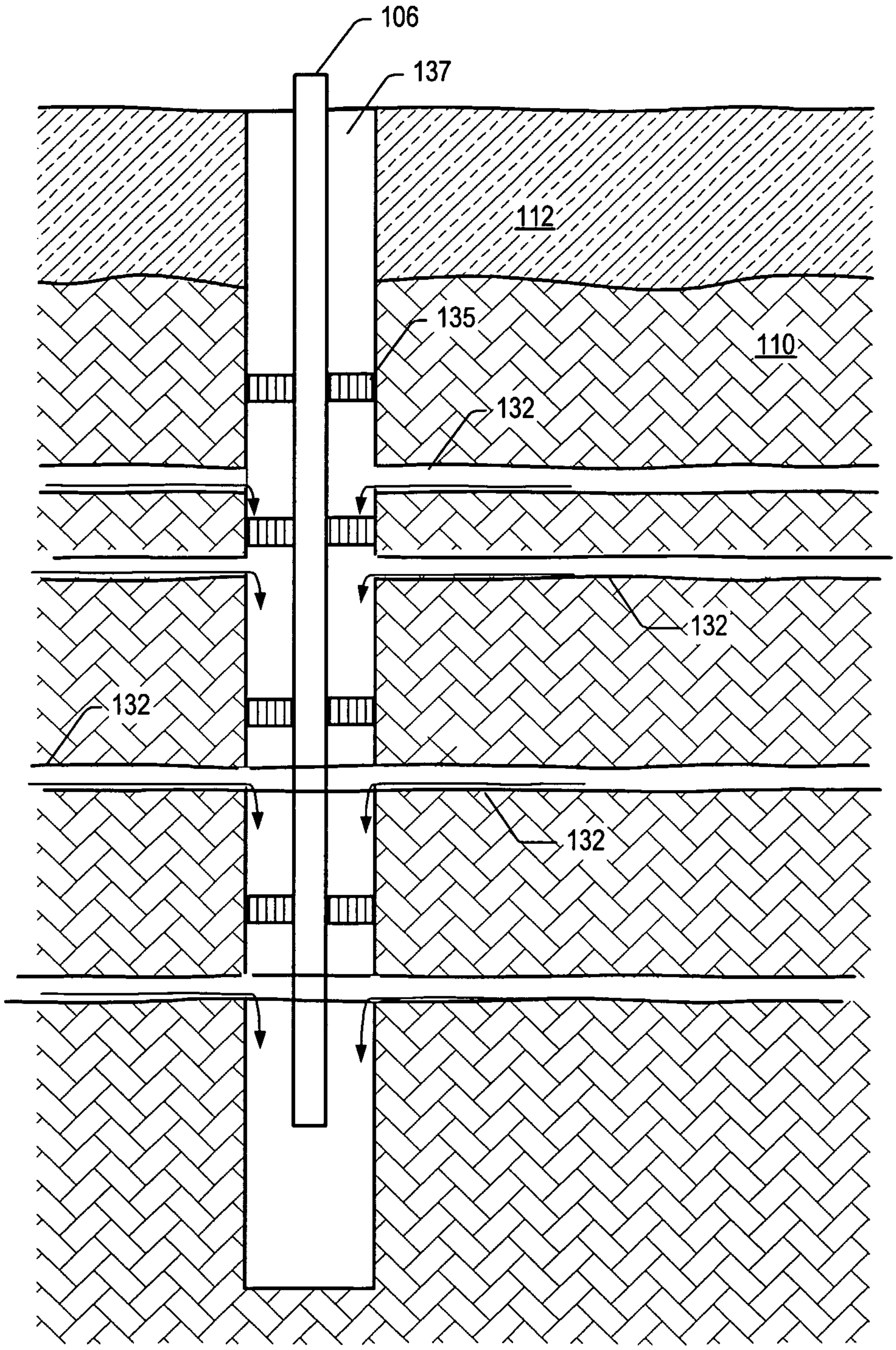


FIG. 11

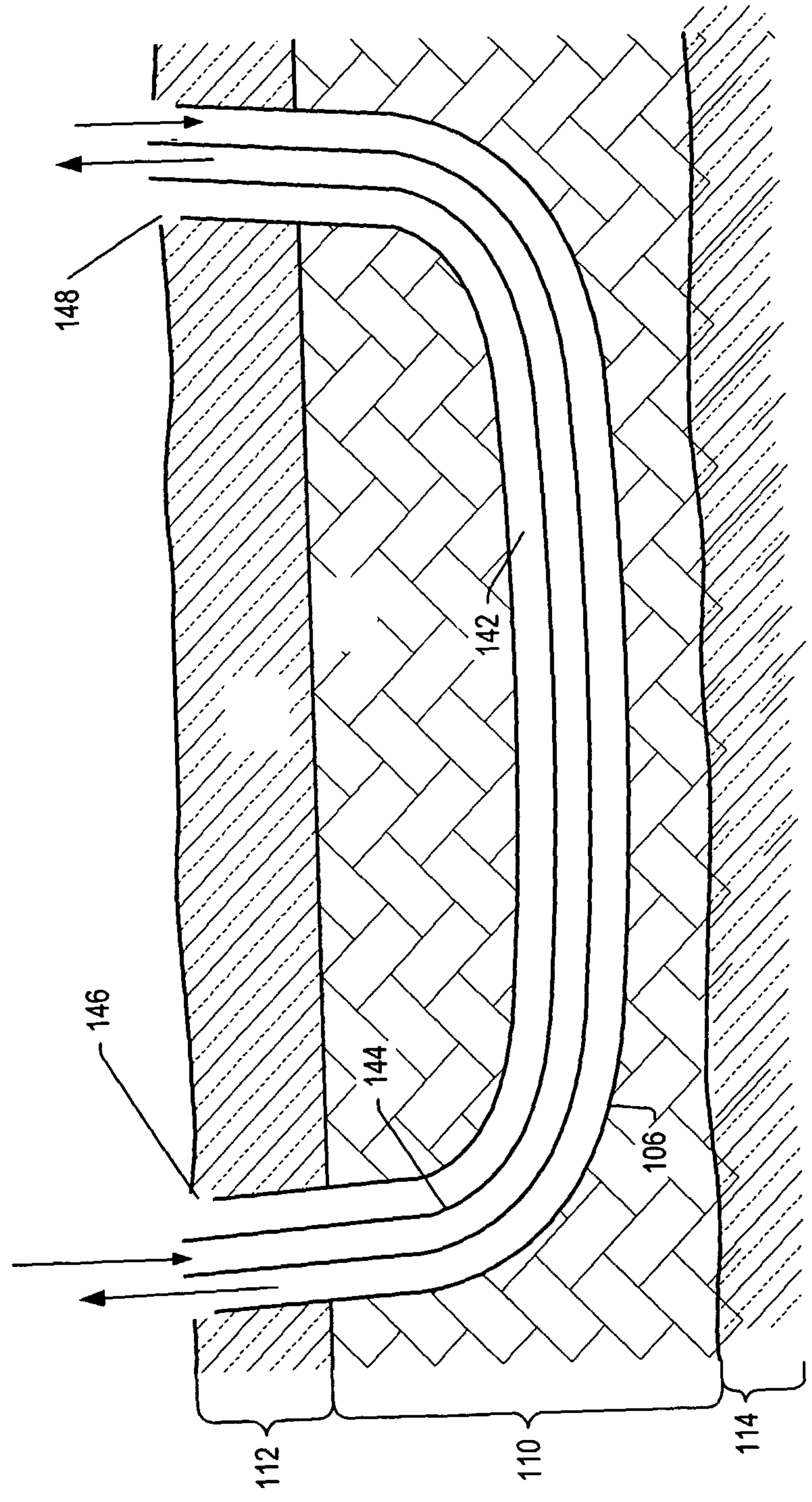


FIG. 12

FIG. 13

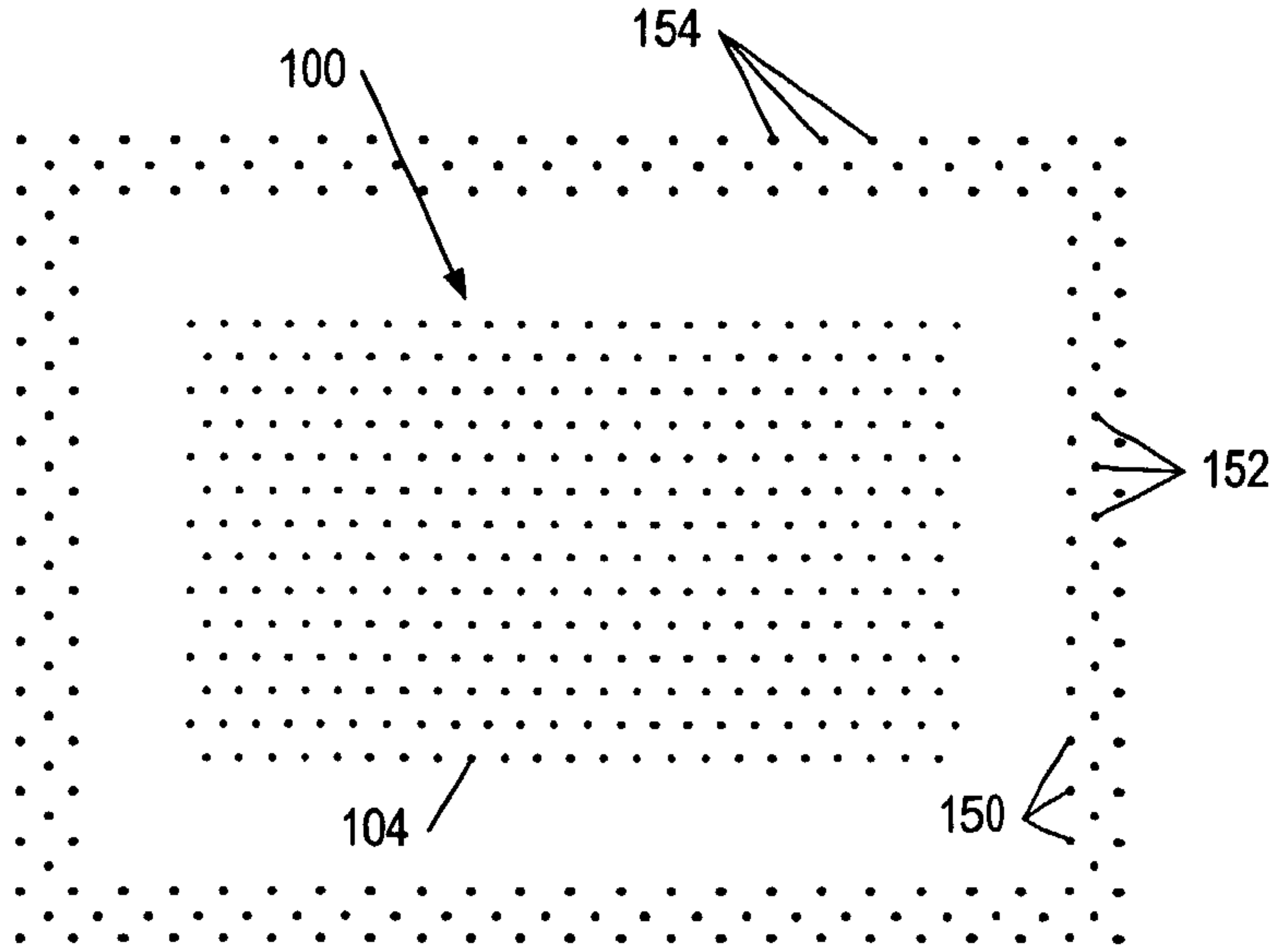


FIG. 14

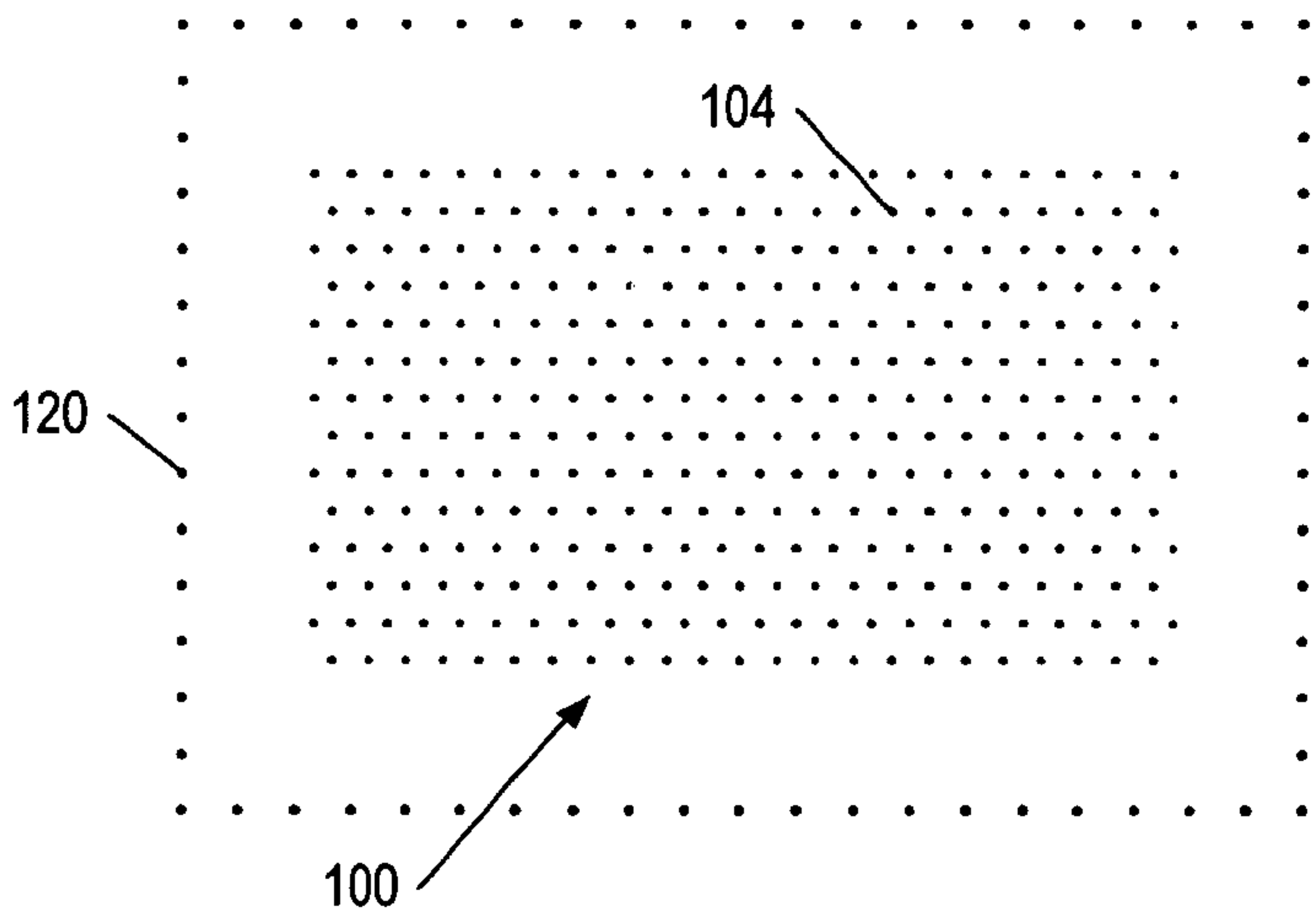
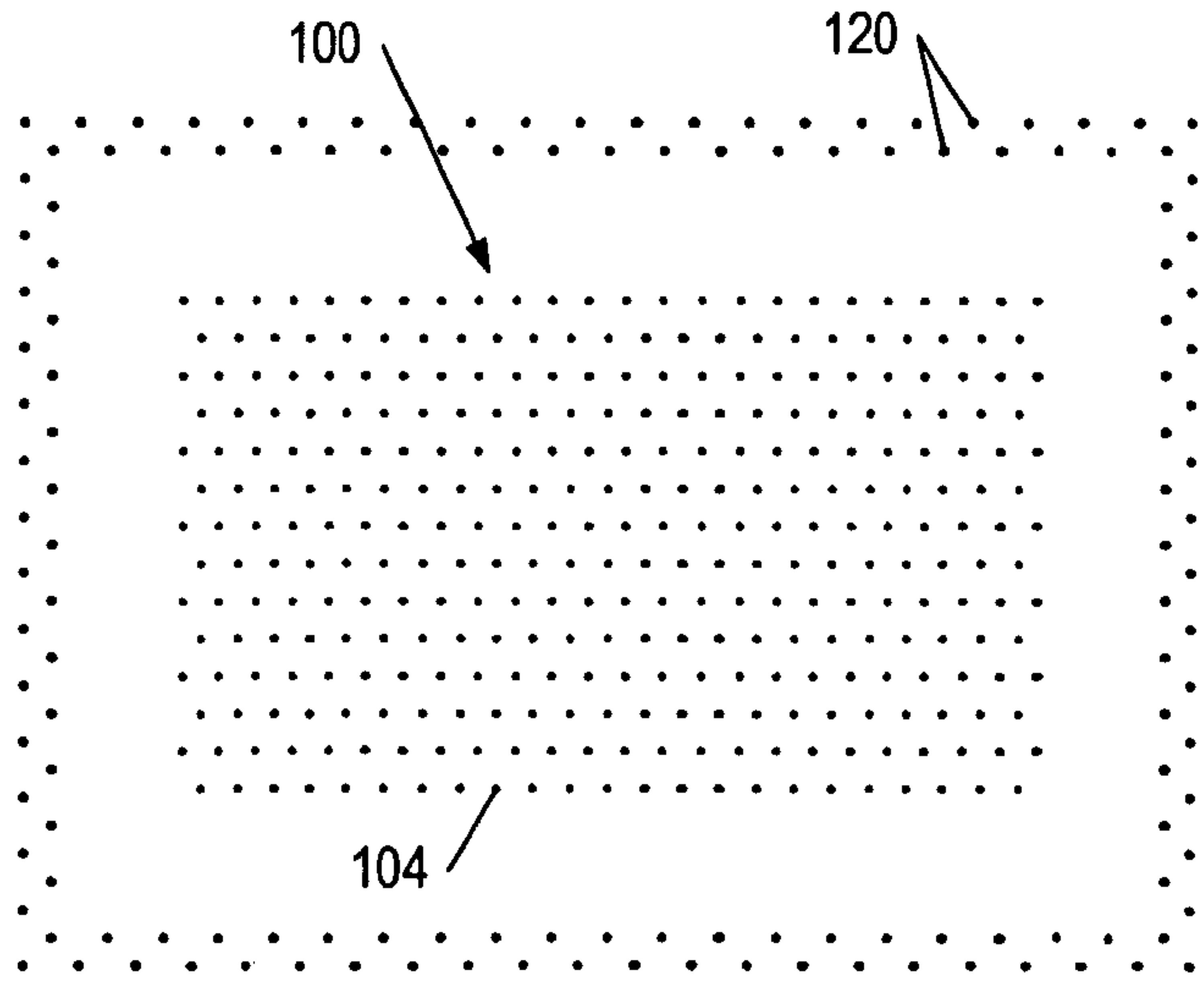


FIG. 15




104
104
104
106
102
108
106
112
116
100
110
116
114
106
108
102
106