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

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2463112 A1 2003/05/01

(21) 2 463 112

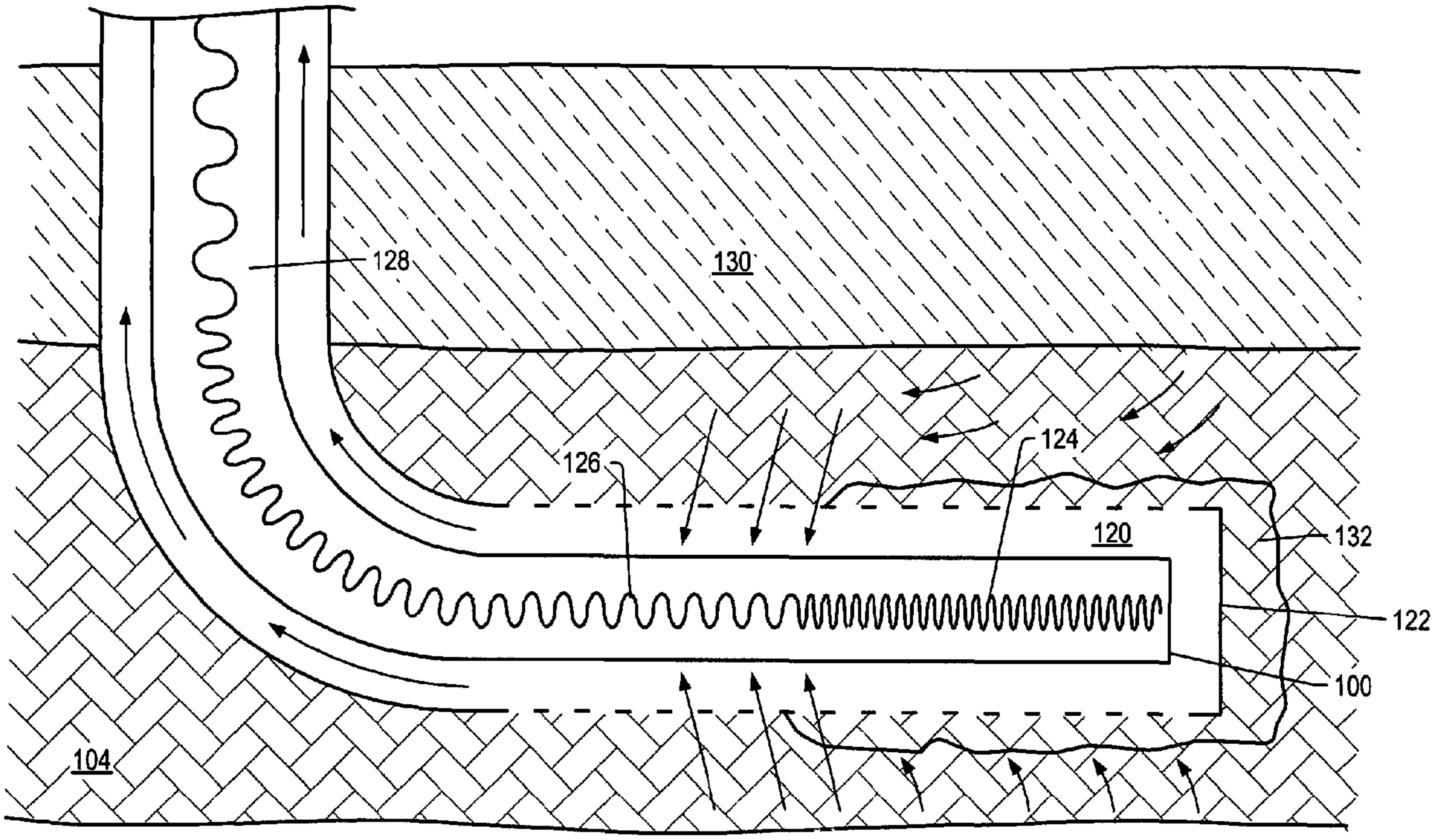
(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(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 2002/034533
(87) **N° publication PCT/PCT Publication No.:** 2003/036038
(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 43/24
(71) **Demandeur/Applicant:**
SHELL CANADA LIMITED, CA
(72) **Inventeurs/Inventors:**
VINEGAR, HAROLD J., US;
WELLINGTON, SCOTT LEE, US;
DE ROUFFIGNAC, ERIC PIERRE, US;
KARANIKAS, JOHN MICHAEL, US
(74) **Agent:** SMART & BIGGAR

(54) Titre : TRAITEMENT THERMIQUE IN SITU D'UNE FORMATION CONTENANT DES HYDROCARBURES PAR PRODUCTION SECONDAIRE A TRAVERS UN PUITS EQUIPE DE RECHAUFFEURS
(54) Title: IN SITU THERMAL PROCESSING OF A HYDROCARBON CONTAINING FORMATION VIA BACKPRODUCING THROUGH A HEATER WELL



(57) **Abrégé/Abstract:**

A process for producing hydrocarbons through a heater wellbore positioned in a hydrocarbon containing formation. The in situ treatment process may include providing heat from one or more heaters to at least a portion of the formation. The heat may be allowed to transfer from one or more heaters to a selected section of the formation. Heat that is allowed to transfer to the selected section may pyrolyze at least some of the hydrocarbons within the selected section. The process may include selectively limiting a temperature proximate a selected portion of a heater wellbore to inhibit coke formation at or near the selected portion.

(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 03/036038 A3

(51) **International Patent Classification^7:** **E21B 43/24**

(21) **International Application Number:** PCT/US02/34533

(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 all designated States except CA)*: **SHELL OIL COMPANY** [US/US]; 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). **DE ROUFFIGNAC, Eric, Pierre**; 4040 Ruskin, Houston, TX 77005 (US). **KARANIKAS, John, Michael**; 4655 Wild Indigo Street, Apt. 302, Houston, TX 77027 (US).

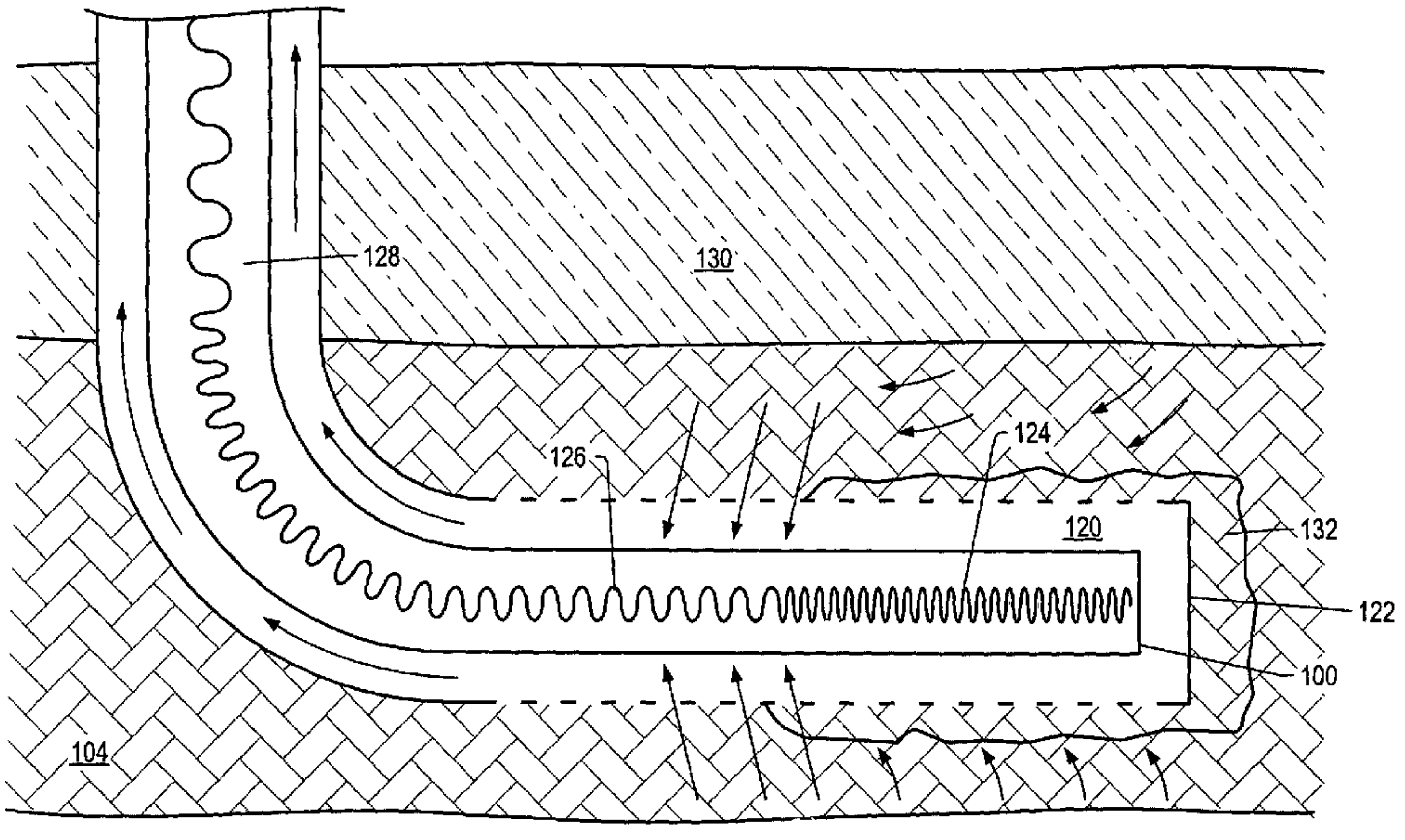
(74) **Agent: CHRISTENSEN, Del, S.**; Shell Oil Company, One Shell Plaza, P.O. Box 2463, Houston, TX 77252-2463 (US).

(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, 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).

[Continued on next page]

(54) Title: IN SITU THERMAL PROCESSING OF A HYDROCARBON CONTAINING FORMATION VIA BACKPRODUCING THROUGH A HEATER WELL



(57) **Abstract:** A process for producing hydrocarbons through a heater wellbore positioned in a hydrocarbon containing formation. The in situ treatment process may include providing heat from one or more heaters to at least a portion of the formation. The heat may be allowed to transfer from one or more heaters to a selected section of the formation. Heat that is allowed to transfer to the selected section may pyrolyze at least some of the hydrocarbons within the selected section. The process may include selectively limiting a temperature proximate a selected portion of a heater wellbore to inhibit coke formation at or near the selected portion.

WO 03/036038 A3

Published:
— *with international search report*

(88) Date of publication of the international search report:
9 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 THERMAL PROCESSING OF A HYDROCARBON CONTAINING FORMATION VIA BACKPRODUCING THROUGH A HEATER WELL

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to methods and systems for production of hydrocarbons, hydrogen, and/or other products from various hydrocarbon containing formations. Certain embodiments relate backproducing through a heater well. Portions of the heater well may be maintained at different temperatures.

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 over declining overall quality of produced hydrocarbons have led to development of processes for more efficient recovery, processing and/or use of available hydrocarbon resources. In situ processes may be used to remove hydrocarbon materials from subterranean formations. Chemical and/or physical properties of hydrocarbon material 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.

As outlined above, there has been a significant amount of effort to develop methods and systems to economically produce hydrocarbons, hydrogen, and/or other products from hydrocarbon containing formations. Production of hydrocarbons, hydrogen, and/or other products from the hydrocarbon contain formations may need numerous production wells. There may be a need to reduce the number of production wells used in a hydrocarbon containing formation. Thus, production of fluids through a heat source wellbore may lead to earlier production of fluids from the 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. One or more heaters 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. In some embodiments, formation fluids may be removed in a vapor phase. In other embodiments, formation fluids may be removed in liquid, vapor phases or as a combination thereof. Temperature and pressure in at least a portion of the formation may be controlled during pyrolysis to yield improved products from the formation.

In an embodiment, a method for treating a hydrocarbon containing formation in situ may include providing heat from one or more heaters to at least a portion of the formation. The method may include allowing the heat to transfer from the one or more heaters to a part of the formation. The heat, which transfers to the part of the formation, may pyrolyze at least some of the hydrocarbons within the part of the formation. The method may include selectively limiting a temperature proximate a selected portion of a heater wellbore. Selectively limiting the temperature may inhibit coke formation at or near the selected portion. The method may also include producing at least some hydrocarbons through the selected portion of the heater wellbore. In some embodiments, a method may include producing a mixture from the part of the formation through a production well.

In an embodiment, selectively limiting the temperature may include providing less heat at the selected portion of the heater wellbore than other portions of the heater wellbore in the selected section. In other embodiments, selectively limiting the temperature may include maintaining the temperature proximate the selected portion below pyrolysis temperatures.

In certain embodiments, a heater wellbore may be placed substantially horizontally within the selected section. Each heater may provide a heat output of less than about 1650 watts per meter. A ratio of energy output of the produced mixture to energy input into the formation may be at least about 5. Heat provided from at least one heater may be transferred to at least a portion of the formation substantially by conduction. The one or more heaters may include at least two heaters, and where heat from at least the two heaters pyrolyzes at least some hydrocarbons within the part of the formation. The method may include providing at least some heat to an overburden section of the heater wellbore to maintain the produced hydrocarbons in a vapor phase.

In other embodiments, pressure in a part of the formation may be maintained below about 150 bars absolute. In some embodiments, the pressure may controlled to be between about 2.0 bars absolute to about 70.0 bars absolute. Hydrocarbons may be produced when a partial pressure of hydrogen in the formation is at least about 0.5 bars absolute.

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 an illustration of stages of heating a hydrocarbon containing formation.

FIG. 2 depicts a schematic view of an embodiment of a portion of an in situ conversion system for treating a hydrocarbon containing formation.

FIG. 3 depicts an embodiment of heater wells located in a hydrocarbon containing formation.

FIG. 4 depicts an embodiment of a heater well with selective heating.

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 generally defined as molecules formed primarily by carbon and hydrogen atoms. Hydrocarbons may also include other elements, such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur.

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.

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.

Hydrocarbons in formations may be treated in various ways to produce many different products. In certain embodiments, such formations may be treated in stages. FIG. 1 illustrates several stages of heating a hydrocarbon containing formation. FIG. 1 also depicts an example of yield (barrels of oil equivalent per ton) (y axis) of formation fluids from a hydrocarbon containing formation versus temperature (°C) (x axis) of the formation.

Desorption of methane and vaporization of water occurs during stage 1 heating. Heating of the formation through stage 1 may be performed as quickly as possible. For example, when a hydrocarbon containing formation is initially heated, hydrocarbons in the formation may desorb adsorbed methane. The desorbed methane may be produced from the formation. If the hydrocarbon containing formation is heated further, water within the hydrocarbon containing formation may be vaporized. Water may occupy, in some hydrocarbon containing formations, between about 10 % to about 50 % of the pore volume in the formation. In other formations, water may occupy larger or smaller portions of the pore volume. Water typically is vaporized in a formation between about 160 °C and about 285 °C for pressures of about 6 bars absolute to 70 bars absolute. In some embodiments, the pressure in a formation may be maintained during an in situ conversion process between about 2 bars absolute and about 70 bars absolute. In some embodiments, the vaporized water may produce wettability changes in the formation and/or increase formation pressure. The wettability changes and/or increased pressure may affect pyrolysis reactions or other reactions in the formation. In certain embodiments, the vaporized water may be produced from the formation. In other embodiments, the vaporized water may be used for steam extraction and/or distillation in the formation or outside the formation. Removing the water from and increasing the pore volume in the formation may increase the storage space for hydrocarbons within the pore volume.

After stage 1 heating, the formation may be heated further, such that a temperature within the formation reaches (at least) an initial pyrolyzation temperature (e.g., a temperature at the lower end of the temperature range shown as stage 2). Hydrocarbons within the formation may be pyrolyzed throughout stage 2. A pyrolysis temperature range may vary depending on types of hydrocarbons within the formation. A pyrolysis temperature range may include temperatures between about 250 °C and about 900 °C. A pyrolysis temperature range for producing desired products may extend through only a portion of the total pyrolysis temperature range. In some embodiments, a pyrolysis temperature range for producing desired products may include temperatures between about 250 °C to about 400 °C. If a temperature of hydrocarbons in a formation is slowly raised through a temperature range from about 250 °C to about 400 °C, production of pyrolysis products may be substantially complete when the temperature approaches 400 °C. Heating the hydrocarbon containing formation with a plurality of heat sources may establish thermal gradients around the heat sources that slowly raise the temperature of hydrocarbons in the formation through a pyrolysis temperature range.

In some in situ conversion embodiments, a temperature of the hydrocarbons to be subjected to pyrolysis may not be slowly increased throughout a temperature range from about 250 °C to about 400 °C. The hydrocarbons in the formation may be heated to a desired temperature (e.g., about 325 °C). Other temperatures may be selected as the desired temperature. Energy input into the formation from the heat sources may be adjusted to maintain the temperature in the formation substantially at the desired temperature. The hydrocarbons may be maintained substantially at the desired temperature until pyrolysis declines such that production of desired formation fluids from the formation becomes uneconomical.

In an in situ conversion process embodiment, a heating rate may be controlled to minimize costs associated with heating a selected section. The costs may include, for example, input energy costs and equipment costs. In certain embodiments, a cost associated with heating a selected section may be minimized by reducing a heating rate when the cost associated with heating is relatively high and increasing the heating rate when the cost associated with heating is relatively low. For example, a heating rate of about 330 watts/m may be used when the associated cost is relatively high, and a heating rate of about 1640 watts/m may be used when the associated cost is relatively low. In certain embodiments, heating rates may be varied between about 300 watts/m and about 800 watts/m when the associated cost is relatively high and between about 1000 watts/m and 1800 watts/m when the associated cost is relatively low. The cost associated with heating may be relatively high at peak times of energy use, such as during the daytime. For example, energy use may be high in warm climates during the daytime in the summer due to energy use for air conditioning. Low times of energy use may be, for example, at night or during weekends, when energy demand tends to be lower. In an embodiment, the heating rate may be varied from a higher heating rate during low energy usage times, such as during the night, to a lower heating rate during high energy usage times, such as during the day.

As shown in FIG. 2, in addition to heat sources 100, one or more production wells 102 will typically be placed within the portion of the hydrocarbon containing formation. Formation fluids may be produced through production wells 102. In some embodiments, production wells 102 may include a heat source. The heat source may heat the portions of the formation at or near the production well and allow for vapor phase removal of formation fluids. The need for high temperature pumping of liquids from the production well may be reduced or eliminated. Avoiding or limiting high temperature pumping of liquids may significantly decrease production costs. Providing heating at or through the production well may: (1) inhibit condensation and/or refluxing of production fluid when such production fluid is moving in the production well proximate the overburden, (2) increase heat input into the formation, and/or (3) increase formation permeability at or proximate the production well. In some in situ conversion process embodiments, an amount of heat supplied to production wells is significantly less than an amount of heat applied to heat sources that heat the formation.

Because permeability and/or porosity increases in the heated formation, produced vapors may flow considerable distances through the formation with relatively little pressure differential. Increases in permeability may result from a reduction of mass of the heated portion due to vaporization of water, removal of hydrocarbons, and/or creation of fractures. Fluids may flow more easily through the heated portion. In some embodiments, production wells may be provided in upper portions of hydrocarbon layers.

FIG. 3 illustrates an embodiment of hydrocarbon containing layer 104 that may be at a near-horizontal angle with respect to an upper surface of ground 106. An angle of hydrocarbon containing layer 104, however, may vary. For example, hydrocarbon containing layer 104 may dip or be steeply dipping. As shown in FIG. 3, production wells 102 may extend into a hydrocarbon containing formation near the top of heated portion 108 heated by heater well 110. Extending production wells significantly into the depth of the heated hydrocarbon layer may be unnecessary.

Fluid generated within a hydrocarbon containing formation may move a considerable distance through the hydrocarbon containing formation as a vapor. The considerable distance may be over 1000 m depending on various factors (e.g., permeability of the formation, properties of the fluid, temperature of the formation, and pressure gradient allowing movement of the fluid). Due to increased permeability in formations subjected to in situ conversion and formation fluid removal, production wells may only need to be provided in every other unit of heat sources or every third, fourth, fifth, or sixth units of heat sources.

During an in situ process, production wells may be operated such that the production wells are at a lower pressure than other portions of the formation. In some embodiments, a vacuum may be drawn at the production wells. Maintaining the production wells at lower pressures may inhibit fluids in the formation from migrating outside of the in situ treatment area.

Certain embodiments may include controlling the heat provided to at least a portion of the formation such that production of less desirable products in the portion may be substantially inhibited. Controlling the heat provided to at least a portion of the formation may also increase the uniformity of permeability within the formation. For example, controlling the heating of the formation to inhibit production of less desirable products may, in some embodiments, include controlling the heating rate to less than a selected amount (e.g., 10 °C, 5 °C, 3 °C, 1 °C, 0.5 °C, or 0.1 °C) per day.

Formations during heating will typically have temperature profiles throughout them, in the context of this patent "substantially uniform" heating means heating such that the temperatures in a majority of the section do not vary by more than 100 °C from the assessed average temperature in the majority of the selected section (volume) being treated.

Substantially uniform heating of the hydrocarbon containing formation may result in a substantially uniform increase in permeability. For example, uniformly heating may generate a series of substantially uniform fractures within the heated portion due to thermal stresses generated in the formation. Heating substantially uniformly may generate pyrolysis fluids from the portion in a substantially homogeneous manner. Water removed due to vaporization and production may result in increased permeability of the heated portion. In addition to creating fractures due to thermal stresses, fractures may also be generated due to fluid pressure increase. As fluids are generated within the heated portion a fluid pressure within the heated portion may also increase. As the fluid pressure approaches a lithostatic pressure of the heated portion, fractures may be generated. Substantially uniform heating and homogeneous generation of fluids may generate substantially uniform fractures within the heated portion. In some embodiments, a permeability of a heated section of a hydrocarbon containing formation may not vary by more than a factor of about 10.

Formation fluids including pyrolyzation fluids may be produced from the formation. The pyrolyzation fluids may include, but are not limited to, hydrocarbons, hydrogen, carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, nitrogen, water, and mixtures thereof. As the temperature of the formation increases, the amount of condensable hydrocarbons in the produced formation fluid tends to decrease. At high temperatures, the formation may produce mostly methane and/or hydrogen. If a hydrocarbon containing formation is heated throughout an entire pyrolysis range, the formation may produce only small amounts of hydrogen towards an upper limit of the pyrolysis range. After all of the available hydrogen is depleted, a minimal amount of fluid production from the formation will typically occur.

Certain embodiments for treating heavy hydrocarbons in a relatively low permeability formation may include providing heat from one or more heat sources to pyrolyze some of the heavy hydrocarbons and then to vaporize a portion of the heavy hydrocarbons. The heat sources may pyrolyze at least some heavy hydrocarbons in a selected section of the formation and may pressurize at least a portion of the selected section. During the heating, the pressure within the formation may increase substantially. The pressure in the formation may be controlled such that the pressure in the formation may be maintained to produce a fluid of a desired composition. Pyrolyzation fluid may be removed from the formation as vapor from one or more heater wells by using the back pressure created by heating the formation.

After pyrolysis of hydrocarbons, a large amount of carbon and some hydrogen may still be present in the formation. A significant portion of remaining carbon in the formation can be produced from the formation in the form of synthesis gas. Synthesis gas generation may take place during stage 3 heating depicted in FIG. 1. Stage 3 may include heating a hydrocarbon containing formation to a temperature sufficient to allow synthesis gas generation. For example, synthesis gas may be produced within a temperature range from about 400 °C to about 1200 °C.

Referring back to FIG. 2, heat sources 100 may include, for example, electric heaters such as insulated conductors, conductor-in-conduit heaters, surface burners, flameless distributed combustors, and/or natural distributed combustors. Heat sources 100 may also include other types of heaters. Heat sources 100 may provide heat to at least a portion of a hydrocarbon containing formation. Energy may be supplied to the heat sources 100 through supply lines 112. The supply lines may be structurally different depending on the type of heat source or heat sources being used to heat the formation. Supply lines for heat sources may transmit electricity for electric heaters, may transport fuel for combustors, or may transport heat exchange fluid that is circulated within the formation.

Production wells 102 may be used to remove formation fluid from the formation. Formation fluid produced from production wells 102 may be transported through collection piping 114 to treatment facilities 116. Formation fluids may also be produced from heat sources 100. For example, fluid may be produced from heat sources 100 to control pressure within the formation adjacent to the heat sources. Fluid produced from heat sources 100 may be transported through tubing or piping to collection piping 114 or the produced fluid may be transported through tubing or piping directly to treatment facilities 116. Treatment facilities 116 may include separation units, reaction units, upgrading units, fuel cells, turbines, storage vessels, and other systems and units for processing produced formation fluids.

An in situ conversion system for treating hydrocarbons may include barrier wells 118. In some embodiments, 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 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.

The composition of products generated from a hydrocarbon containing formation may be altered by controlling conditions within a treatment area and/or within one or more surface treatment units. Conditions within the treatment area and/or one or more surface treatment units which affect product composition include, but are not limited to, average temperature, fluid pressure, partial pressure of H_2, temperature gradients, composition of formation material, heating rates, and composition of fluids entering the treatment area and/or the surface treatment unit.

Controlling formation conditions to control the pressure of hydrogen in the produced fluid may result in improved qualities of the produced fluids. In some embodiments, it may be desirable to control formation conditions so that the partial pressure of hydrogen in a produced fluid is greater than about 0.5 bars absolute, as measured at a production well.

In one embodiment, a method of treating a hydrocarbon containing formation in situ may include adding hydrogen to the selected section after a temperature of the selected section is at least about 270 °C. Other embodiments may include controlling a temperature of the formation by selectively adding hydrogen to the formation.

In an embodiment, a portion of a hydrocarbon containing formation may be heated to increase a partial pressure of H_2. In some embodiments, an increased H_2 partial pressure may include H_2 partial pressures in a range from about 0.5 bars to about 7 bars, or, in some embodiments, range from about 5 bars to about 7 bars. For example, a majority of hydrocarbon fluids may be produced wherein a H_2 partial pressure is within a range of about 5 bars to about 7 bars. A range of H_2 partial pressures within the pyrolysis H_2 partial pressure range may vary depending on, for example, temperature and pressure of the heated portion of the formation.

An in situ conversion process may generate significant amounts of H_2 and hydrocarbon fluids within the formation. Generation of hydrogen within the formation, and pressure within the formation sufficient to force hydrogen into a liquid phase within the formation, may produce a reducing environment within the formation without the need to introduce a reducing fluid (e.g., H_2 and/or non-condensable saturated hydrocarbons) into the formation. A hydrogen component of formation fluid produced from the formation may be separated and used for desired purposes. The desired purposes may include, but are not limited to, fuel for fuel cells, fuel for combustors, and/or a feed stream for surface hydrogenation units.

In an embodiment, a method for treating a hydrocarbon containing formation in situ may include adding hydrogen to a selected section of the formation when the selected section is at or undergoing certain conditions. For example, the hydrogen may be added through a heater well or production well located in or proximate the selected section. Since hydrogen is sometimes in relatively short supply (or relatively expensive to make or procure), hydrogen may be added when conditions in the formation optimize the use of the added hydrogen. For example, hydrogen produced in a section of a formation undergoing synthesis gas generation may be added to a section of the formation undergoing pyrolysis. The added hydrogen in the pyrolysis section of the formation may promote formation of aliphatic compounds and inhibit formation of olefinic compounds that reduce the quality of hydrocarbon fluids produced from formation.

In some embodiments, hydrogen may be added to the selected section after an average temperature of the formation is at a pyrolysis temperature (e.g., when the selected section is at least about 270 °C). In some embodiments, hydrogen may be added to the selected section after the average temperature is at least about 290 °C, 320 °C, 375 °C, or 400 °C. Hydrogen may be added to the selected section before an average temperature of the formation is about 400 °C. In some embodiments, hydrogen may be added to the selected section before the average temperature is about 300 °C or about 325 °C.

The average temperature of the formation may be controlled by selectively adding hydrogen to the selected section of the formation. Hydrogen added to the formation may react in exothermic reactions. The exothermic reactions may heat the formation and reduce the amount of energy that needs to be supplied from heat sources to the formation. In some embodiments, an amount of hydrogen may be added to the selected section of the formation such that an average temperature of the formation does not exceed about 400 °C.

A valve may maintain, alter and/or control a pressure within a heated portion of a hydrocarbon containing formation. For example, a heat source disposed within a hydrocarbon containing formation may be coupled to a valve. The valve may release fluid from the formation through the heat source. In addition, a pressure valve may be coupled to a production well within the hydrocarbon containing formation. In some embodiments, fluids released by the valves may be collected and transported to a surface unit for further processing and/or treatment.

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.

Hydrocarbons to be subjected to in situ conversion may be located under a large area. The in situ conversion system may be used to treat small portions of the formation, and other sections of the formation may be treated as time progresses. In an embodiment of a system for treating a formation (e.g., an oil shale formation), a field layout for 24 years of development may be divided into 24 individual plots that represent individual drilling years. Each plot may include 120 “tiles” (repeating matrix patterns) wherein each plot is made of 6 rows by 20 columns of tiles. Each tile may include 1 production well and 12 or 18 heater wells. The heater wells may be placed in an equilateral triangle pattern with a well spacing of about 12 m.

Exact placement of heater wells, production wells, etc. will depend on variables specific to the formation (e.g., thickness of the layer or composition of the layer), project economics, etc. In certain embodiments, heater wells may be substantially horizontal while production wells may be vertical, or vice versa. In some embodiments, wells may be aligned along dip or strike or oriented at an angle between dip and strike.

The spacing between heat sources may vary depending on a number of factors. The factors may include, but are not limited to, the type of a hydrocarbon containing formation, the selected heating rate and/or the selected average temperature to be obtained within the heated portion. In some well pattern embodiments, the spacing between heat sources may be within a range of about 5 m to about 25 m. In some well pattern embodiments, spacing between heat sources may be within a range of about 8 m to about 15 m. Heat sources may be located within the formation such that spacing between each heat source varies by less than approximately 10 %, 20 % or 30 %. In addition, heat sources may be disposed such that an approximately equal space exists between each of the heat sources.

When production of hydrocarbons from the formation is inhibited, the pressure in the formation tends to increase with temperature in the formation because of thermal expansion and/or phase change of heavy hydrocarbons and other fluids (e.g., water) in the formation. Pressure within the formation may have to be maintained below a selected pressure to inhibit unwanted production, fracturing of the overburden or underburden, and/or coking of hydrocarbons in the formation. The selected pressure may be a lithostatic or hydrostatic pressure of the formation. For example, the selected pressure may be about 150 bars absolute or, in some embodiments, the selected pressure may be about 35 bars absolute. The pressure in the formation may be controlled by controlling production rate from production wells in the formation. In other embodiments, the pressure in the formation is controlled by releasing pressure through one or more pressure relief wells in the formation. Pressure relief wells may be heat sources or separate wells inserted into the formation. Formation fluid removed from the formation through the relief wells may be sent to a surface facility. Producing at least some hydrocarbons from the formation may inhibit the pressure in the formation from rising above the selected pressure.

In certain embodiments, some formation fluids may be back produced through a heat source wellbore. For example, some formation fluids may be back produced through a heat source wellbore during early times of heating of a hydrocarbon containing formation. In an embodiment, some formation fluids may be produced through a portion of a heat source wellbore. Injection of heat may be adjusted along the length of the wellbore so that fluids produced through the wellbore are not overheated. Fluids may be produced through portions of the heat source wellbore that are at lower temperatures than other portions of the wellbore.

Producing at least some formation fluids through a heat source wellbore may reduce or eliminate the need for additional production wells in a formation. In addition, pressures within the formation may be reduced by producing fluids through a heat source wellbore (especially within the region surrounding the heat source wellbore). Reducing pressures in the formation may alter the ratio of produced liquids to produced vapors. In certain embodiments, producing fluids through the heat source wellbore may lead to earlier production of fluids from the formation. Portions of the formation closest to the heat source wellbore will increase to mobilization and/or pyrolysis temperatures earlier than portions of the formation near production wells. Thus, fluids may be produced at earlier times from portions near the heat source wellbore.

FIG. 4 depicts an embodiment of a heater well for selectively heating a formation. Heat source 100 may be placed in opening 120 in hydrocarbon containing layer 104. In certain embodiments, opening 120 may be a substantially horizontal opening within hydrocarbon layer 104. Perforated casing 122 may be placed in opening

120. Perforated casing 122 may provide support from hydrocarbon and/or other material in hydrocarbon layer 104 collapsing opening 120. Perforations in perforated casing 122 may allow for fluid flow from hydrocarbon layer 104 into opening 120. Heat source 100 may include hot portion 124. Hot portion 124 may be a portion of heat source 100 that operates at higher heat outputs of a heat source. For example, hot portion 124 may output between about 650 watts per meter and about 1650 watts per meter. Hot portion 124 may extend from a "heel" of the heat source to the end of the heat source (i.e., the "toe" of the heat source). The heel of a heat source is the portion of the heat source closest to the point at which the heat source enters a hydrocarbon layer. The toe of a heat source is the end of the heat source furthest from the entry of the heat source into a hydrocarbon layer.

In an embodiment, heat source 100 may include warm portion 126. Warm portion 126 may be a portion of heat source 100 that operates at lower heat outputs than hot portion 124. For example, warm portion 126 may output between about 150 watts per meter and about 650 watts per meter. In certain embodiments, warm portion 126 may maintain a temperature below pyrolysis temperatures. Warm portion 126 may be located closer to the heel of heat source 100. In certain embodiments, warm portion 126 may be a transition portion (i.e., a transition conductor) between hot portion 124 and overburden portion 128. Overburden portion 128 may be located within overburden 130. Overburden portion 128 may provide a lower heat output than warm portion 126. For example, overburden portion may output between about 30 watts per meter and about 90 watts per meter. In some embodiments, overburden portion 128 may provide as close to no heat (0 watts per meter) as possible to overburden 130. Some heat, however, may be used to maintain fluids produced through opening 120 in a vapor phase within overburden 130.

In certain embodiments, hot portion 124 of heat source 100 may heat hydrocarbons to high enough temperatures to result in coke 132 forming in hydrocarbon layer 104. Coke 132 may occur in an area surrounding opening 120. Warm portion 126 may be operated at lower heat outputs such that coke does not form at or near the warm portion of heat source 100. Coke 132 may extend radially from opening 120 as heat from heat source 100 transfers outward from the opening. At a certain distance, however, coke 132 no longer forms because temperatures in hydrocarbon layer 104 at the certain distance will not reach coking temperatures. The distance at which no coke forms may be a function of heat output (watts per meter from heat source 100), type of formation, hydrocarbon content in the formation, and/or other conditions within the formation.

The formation of coke 132 may inhibit fluid flow into opening 120 through the coking. Fluids in the formation may, however, be produced through opening 120 at the heel of heat source 100 (i.e., at warm portion 126 of the heat source) where there is no coke formation. The lower temperatures at the heel of heat source 100 may reduce the possibility of increased cracking of formation fluids produced through the heel. Fluids may flow in a horizontal direction through the formation more easily than in a vertical direction. Typically, horizontal permeability in a relatively permeable formation (e.g., a tar sands formation) is about 5 to 10 times greater than vertical permeability. Thus, fluids may flow along the length of heat source 100 in a substantially horizontal direction. Producing formation fluids through opening 120 may be possible at earlier times than producing fluids through production wells in hydrocarbon layer 104. The earlier production times through opening 120 may be possible because temperatures near the opening increase faster than temperatures further away due to conduction of heat from heat source 100 through hydrocarbon layer 104. Early production of formation fluids may be used to maintain lower pressures in hydrocarbon layer 104 during start-up heating of the formation (i.e., before production begins at production wells in the formation). Lower pressures in the formation may increase liquid production from the formation. In addition, producing formation fluids through opening 120 may reduce the number of production wells needed in the formation.

Alternately, in certain embodiments portions of a heater may be moved or removed, thereby shortening the heated section. For example, in a horizontal well the heater may initially extend to the "toe." As products are produced from the formation, the heater may be moved so that it is placed at location further from the "toe." Heat may be applied to a different portion of the formation.

In some embodiments, the ratio of energy output of the formation to energy input into the formation may be increased by producing a larger percentage of heavy hydrocarbons versus light hydrocarbons from the formation. The energy content of heavy hydrocarbons tends to be higher than the energy content of light hydrocarbons. Producing more heavy hydrocarbons may increase the ratio of energy output to energy input. In addition, production costs (such as heat input) for heavy hydrocarbons from a relatively permeable formation may be less than production costs for light hydrocarbons. In certain embodiments, the energy output to energy input ratio is at least about 5. In other embodiments, the energy output to energy input ratio is at least about 6 or at least about 7. In general, energy output to energy input ratios for in situ production from a relatively permeable formation may be improved versus typical production techniques. For example, steam production of heavy hydrocarbons typically have energy ratios between about 2.7 and about 3.3. Steam production may also produce about 28 % to about 40 % of the initial hydrocarbons in place from the formation. In situ production from a relatively permeable formation may produce, in certain embodiments, greater than about 50 % of the initial hydrocarbons in place.

In an embodiment for treating a relatively permeable formation, mobilized fluids may be produced from the formation with limited or no pyrolyzing and/or upgrading of the mobilized fluids. The produced fluids may be further treated in a surface facility located near the formation or at a remotely located surface facility. The produced fluids may be treated such that the fluids can be transported (e.g., by pipeline, ship, etc.). Heat sources in such an embodiment may have a larger spacing than may be needed for producing pyrolyzed formation fluids. For example, a spacing between heat sources may be about 15 m, about 30 m, or even about 40 m for producing substantially un-pyrolyzed fluids from a relatively permeable formation. An average temperature of the formation may be between about 50 °C and about 225 °C, or, in some embodiments, between about 150 °C and about 200 °C or between about 100 °C and about 150 °C. For example, a well spacing of about 30 m may produce an average temperature in the formation of about 150 °C in about ten years, assuming a constant heat output from the heat sources. Smaller heat source spacings may be used to increase a temperature rise within the formation. For example, a well spacing of about 15 m will tend to produce an average temperature in the formation of about 150 °C in less than about a year. Larger well spacings may decrease costs associated with, but not limited to, forming wellbores, purchasing and installing heating equipment, and providing energy to heat the formation.

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

CLAIMS

1. A method for treating a hydrocarbon containing formation in situ, comprising:

providing heat from one or more heaters to at least a portion of the formation;

allowing the heat to transfer from the one or more heaters to a part of the formation such that the heat pyrolyzes at least some hydrocarbons in the part of the formation;

providing less heat proximate to a selected portion of a heater wellbore than other portions of the heater wellbore in the part of the formation to limit a temperature and inhibit coke formation at or near the selected portion of the heater wellbore; and

producing at least some hydrocarbons through the selected portion of the heater wellbore.

2. The method of claim 1, further comprising generating or providing water in or proximate to the selected portion of the heater wellbore to inhibit coke formation at or near the selected portion of the heater wellbore.

3. The method according to one or more of claims 1 to 2, wherein the heater wellbore is placed substantially horizontally within the part of the formation.

4. The method according to one or more of claims 1 to 3, wherein limiting the temperature comprises maintaining the temperature proximate the selected portion of the heater wellbore below pyrolysis temperatures.

5. The method according to one or more of claims 1 to 4, further comprising producing a mixture from the part of the formation through a production well.

6. The method according to one or more of claims 1 to 5, further comprising providing at least some heat to an overburden section of the heater wellbore to maintain the produced hydrocarbons in a vapor phase.

7. The method according to one or more of claims 1 to 6, further comprising maintaining a pressure in the part of the formation below about 150 bars absolute.

8. The method according to one or more of claims 1 to 7, further comprising producing

hydrocarbons when a partial pressure of hydrogen in the formation is at least about 0.5 bars absolute.

9. The method according to one or more of claims 1 to 8, wherein the heat provided from at least one heater is transferred to at least a portion of the formation substantially by conduction.

10. The method according to one or more of claims 1 to 9, wherein a ratio of energy output of the produced mixture to energy input into the formation is at least about 5.

11. The method according to one or more of claims 1 to 10, wherein each heater provides a heat output of less than about 1650 watts per meter.

12. The method according to one or more of claims 1 to 11, controlling a pressure within at least a majority of the part of the formation, wherein the pressure is between about 2.0 bar absolute and about 70.0 bar absolute.

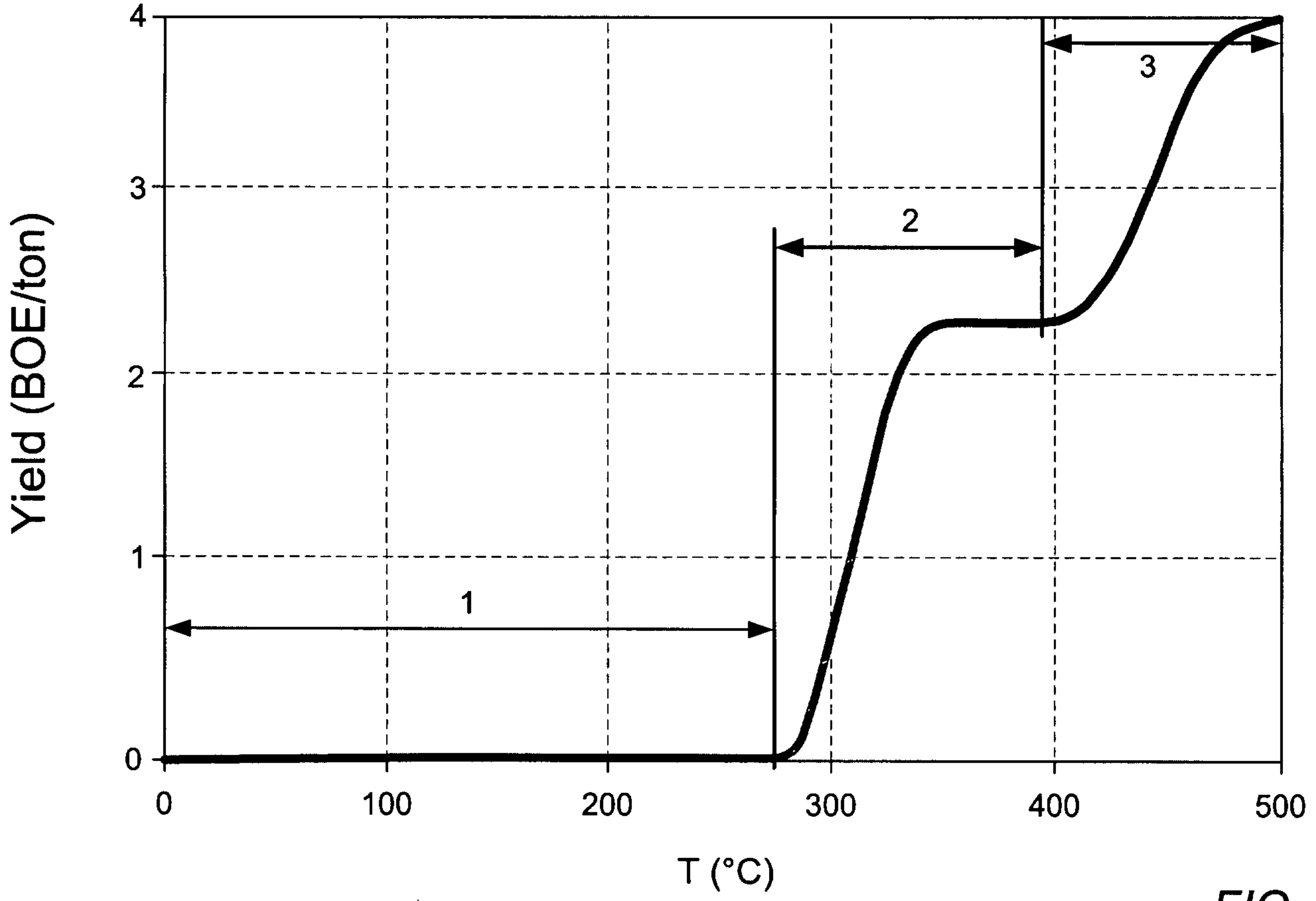


FIG. 1

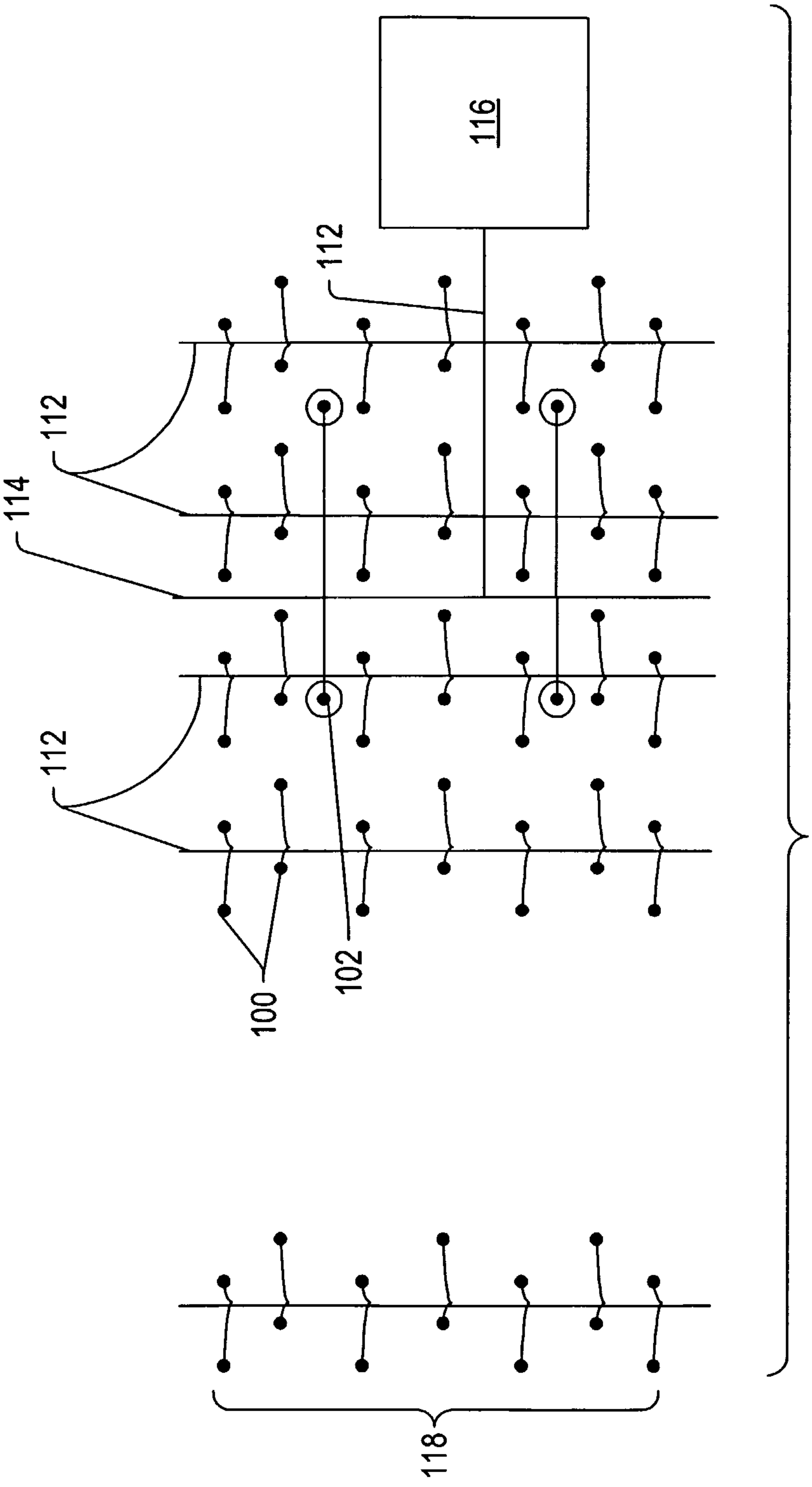


FIG. 2

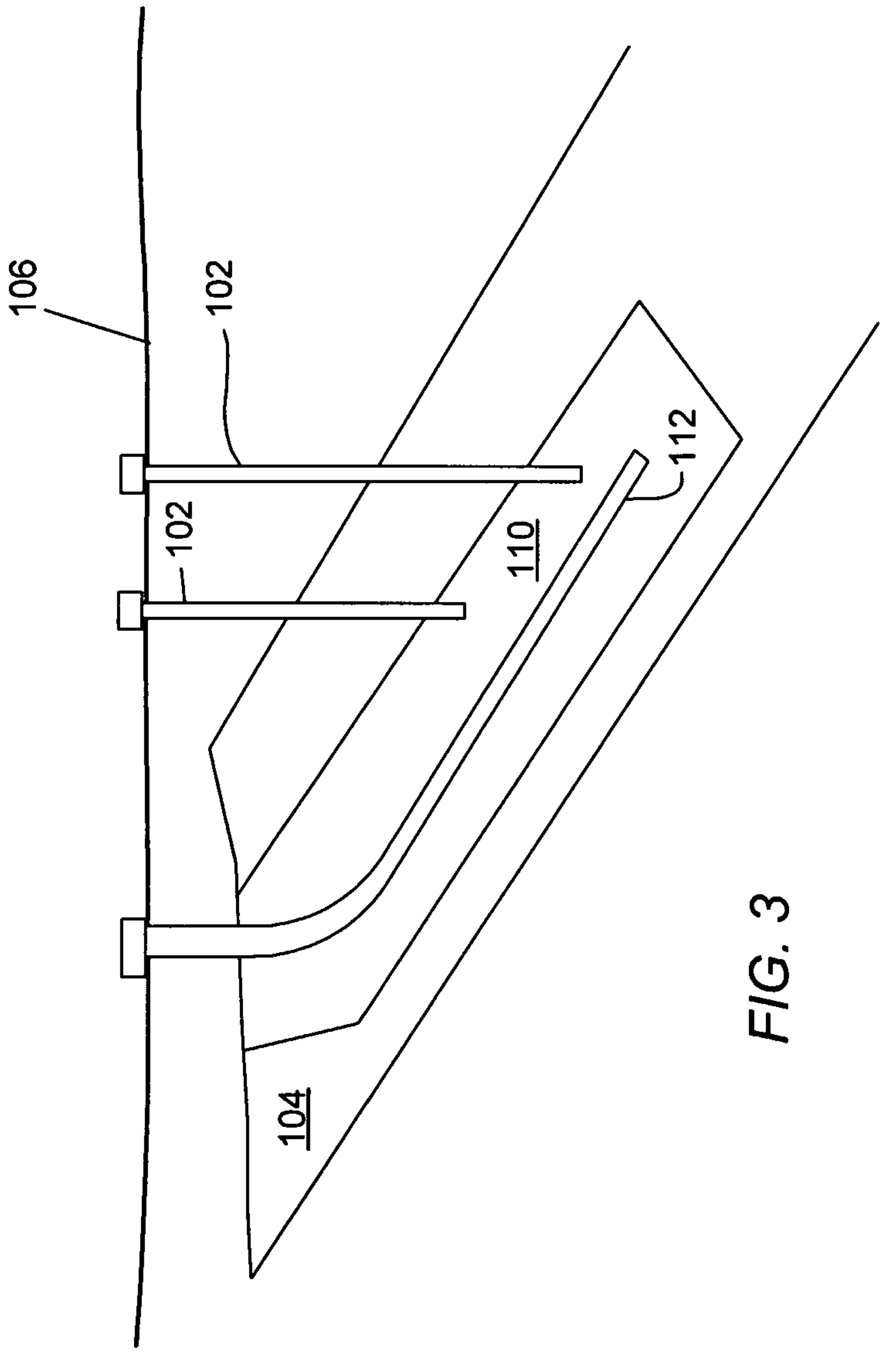


FIG. 3

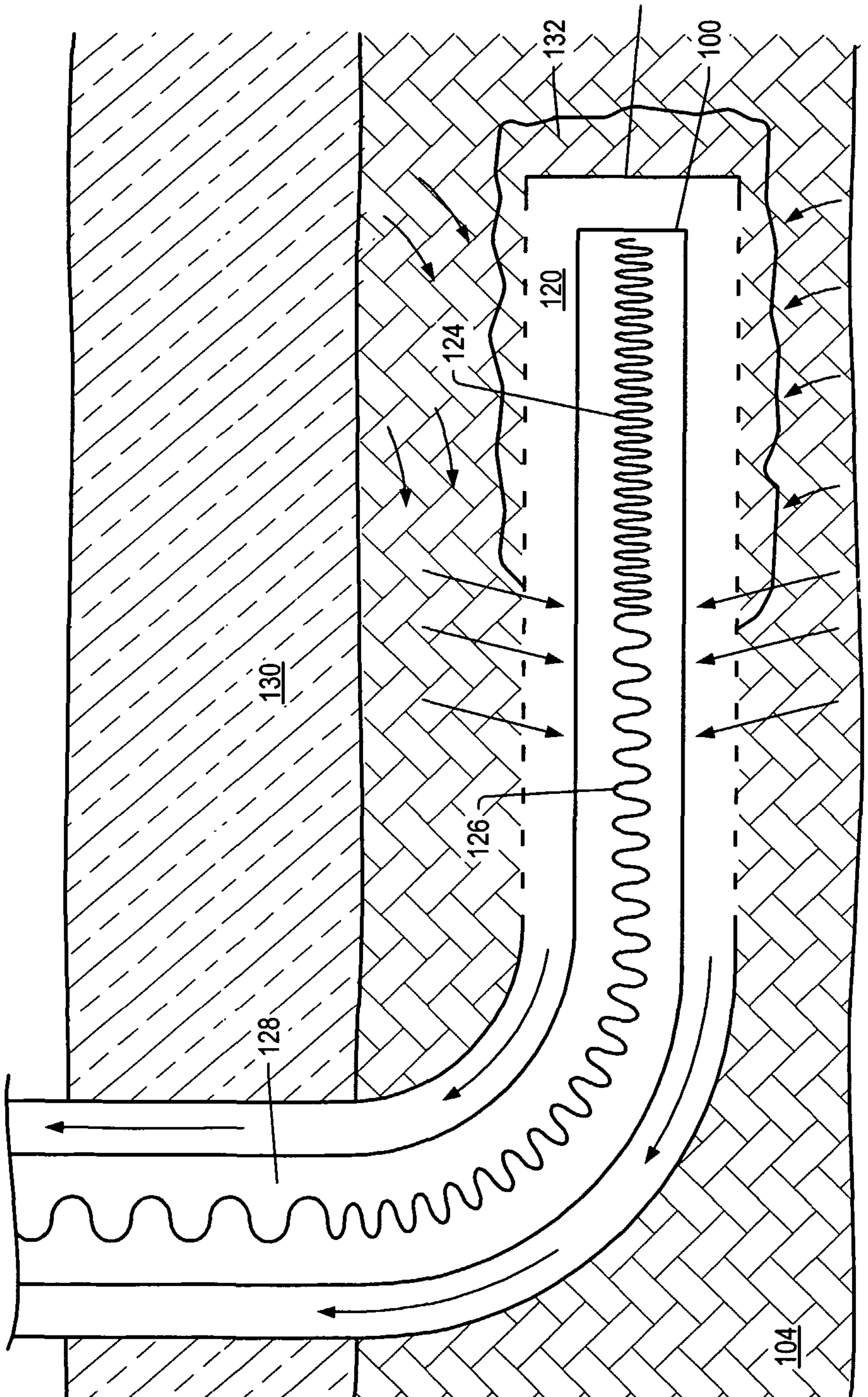
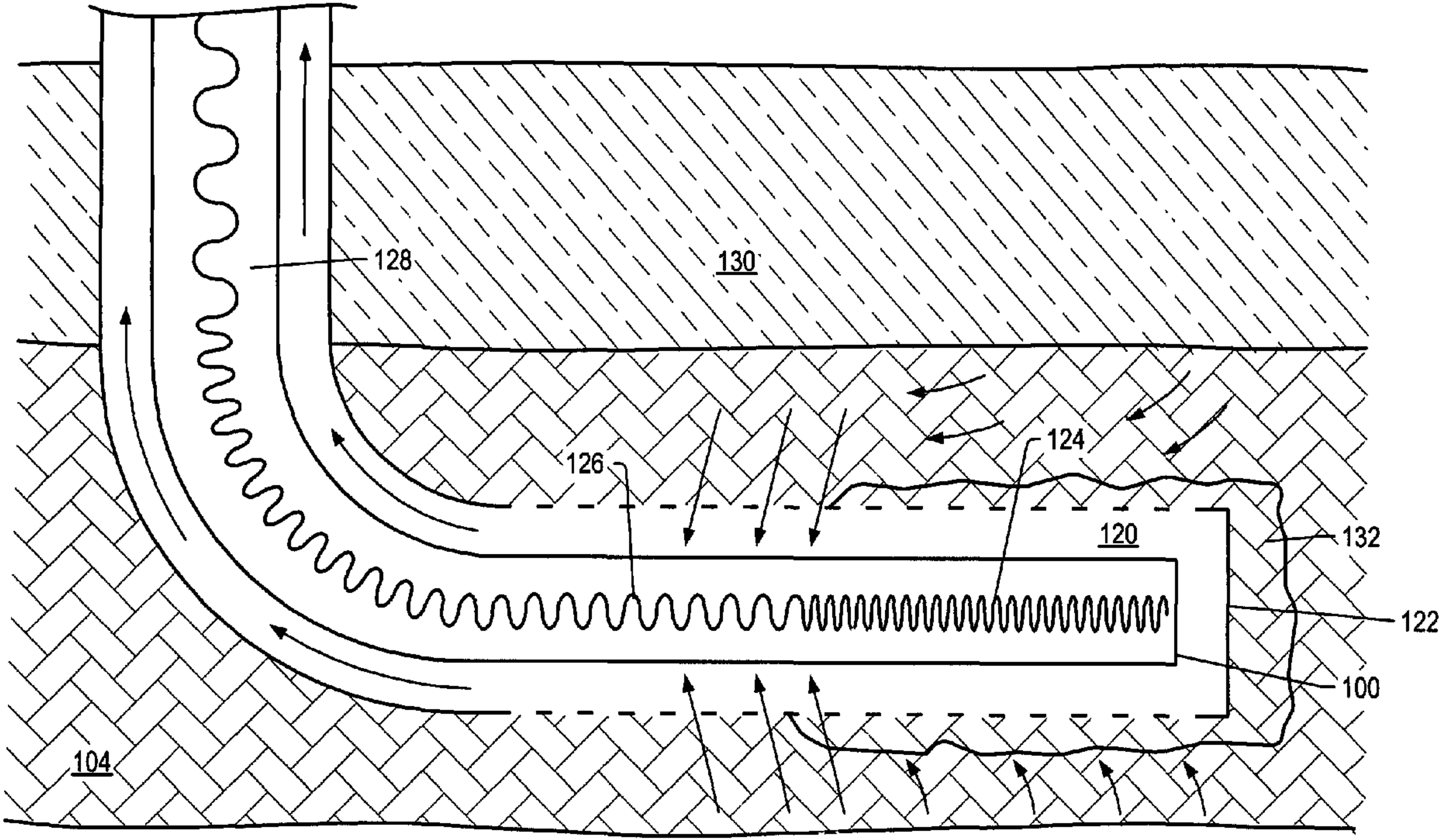


FIG. 4


128
130
124
126
120
132
122
100
104