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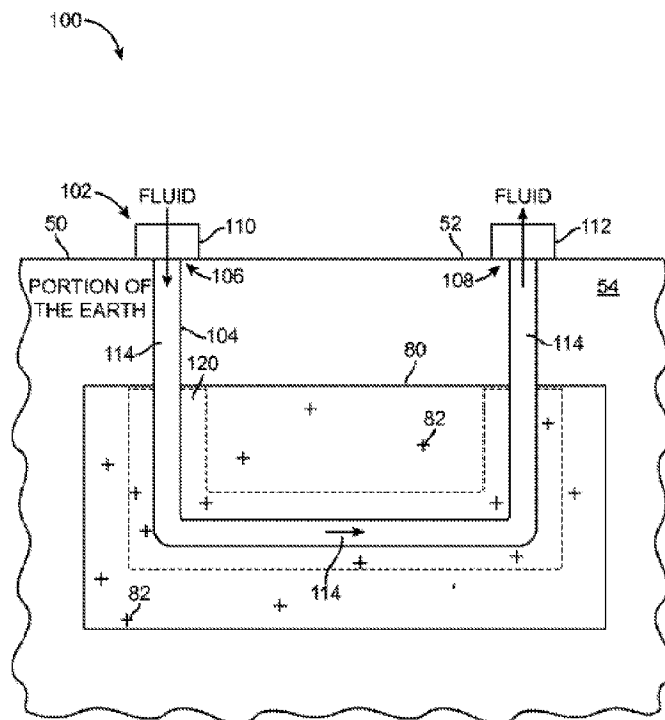


FIGURE 2

(57) **Abrégé/Abstract:**

The present disclosure relates generally to methods and systems for production of hydrocarbons from various subsurface formations such as hydrocarbon containing formations. In particular, certain embodiments relate to using a closed loop circulation system in reservoirs of heavy hydrocarbons for heating a portion of the formation during a process that reduces the viscosity of the heavy thereby making it able to flow.

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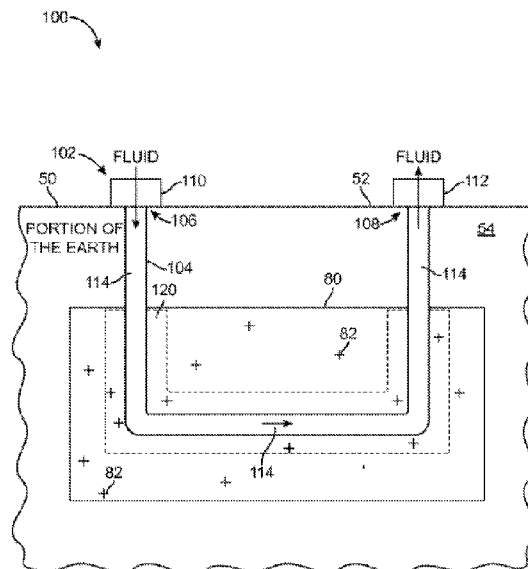


FIGURE 2

(57) Abstract: The present disclosure relates generally to methods and systems for production of hydrocarbons from various subsurface formations such as hydrocarbon containing formations. In particular, certain embodiments relate to using a closed loop circulation system in reservoirs of heavy hydrocarbons for heating a portion of the formation during a process that reduces the viscosity of the heavy thereby making it able to flow.

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CLOSED LOOP ENHANCED OIL RECOVERY

CROSS-REFERENCE TO RELATED APPLICATION

5 This application claims the benefit of U.S. Provisional Application No. 62/406,102, entitled "CLOSED LOOP ENHANCED OIL RECOVERY," filed October 10, 2016, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

10 Hydrocarbons, particularly heavy hydrocarbons, obtained from subterranean formations are often used as energy resources, as feedstocks, and as consumer products. Concerns over depletion of available hydrocarbon resources and concerns over declining overall quality of produced hydrocarbons have led to development of processes for more efficient recovery, processing and/or use of available hydrocarbon resources. *In situ* processes may be used to
15 remove hydrocarbon materials from subterranean formations. The chemical and/or physical properties of the hydrocarbon material in subterranean formations may need to be changed to allow the hydrocarbon material to be more easily removed from the subterranean formation. Examples of chemical and physical changes may include *in situ* reactions that produce removable fluids, composition changes, solubility changes, density changes, phase changes,
20 and/or viscosity changes of the hydrocarbon material in the formation. In some cases, heaters may be placed in wellbores to heat a formation during an *in situ* process. U.S. Pat. No. 7,575,052 discloses in more detail heat sources, which may be used to heat a subterranean formation. *In-situ* thermal conduction, in the past, has been slow, and thus considered impractical for heavy oil recovery.

25 In oil shale work, attempts have been made to visualize alternatives to the use of expensive electric heating. Transferring heat directly from a heater to the formation would save almost half the energy of electric heating. In some production processes, high temperature circulating fluids in pipes have been used to efficiently transmit heat by convection. In refineries, molten salts are pumped in pipes to transfer intense heat.

There is a need in the art for cost effective methods for enhanced oil recovery using thermal conduction. Provided herein are systems and methods addressing these and other needs in the art.

SUMMARY

5 In general terms, this disclosure is directed to heating an underground reservoir, particularly an underground reservoir comprised of heavy oils. This disclosure's main purpose is to reduce the viscosity of the heavy oil to a point at which the fluids become mobile and flow at an economic rate. The process of this disclosure involves heat conduction, which has, in the past been considered less efficient than convective heat transfer, as discussed in the
10 Background. Operational expenditures may, however, be minimized in this disclosure. If steam, for example, is used in the closed loop, there is no water lost, and there is little concern about multi-phase flow. The circulating fluid can, however, be any fluid that allows for the greatest heat transfer to the reservoir fluids. Various aspects are described in this disclosure.

In one possible configuration and by non-limiting example, a fully enclosed wellbore is
15 formed through an underground reservoir that contains an oil shale formation/heavy oil. In some embodiments, the heavy hydrocarbon can have an API gravity of less than 20° (e.g., an API gravity of less than 10°). In some embodiments, the heavy hydrocarbon can have a density of at least 1,000 kg/m³. In some embodiments, the heavy hydrocarbon can have a viscosity of at least 100 centipoise at 15°C. In some embodiments, the portion of the reservoir can have a
20 permeability of 10 millidarcy or more (e.g., 100 millidarcy or more).

A fluid is passed through the wellbore to heat the shale/heavy oil. The temperature of the heating fluid can be greater than the temperature of the heavy hydrocarbon in the heavy hydrocarbon reservoir. In some cases, the temperature of the heating fluid is an initial
25 temperature of the heating fluid before the heating fluid passes through the portion of the heavy hydrocarbon reservoir. In some embodiments, the heating fluid can have a temperature of from 700°C to 920°C (e.g., from 770°C to 870°C, or from 800°C to 850°C). The wellbore formed in the underground reservoir can include first and second ends. The first end and the second ends of the wellbore may be coupled to a first wellhead and a second wellhead, respectively.

As discussed herein, the heating fluid can be steam. In some examples, the heating
30 fluid can be a hydrocarbon supplied from a hydrocarbon well after extraction of the hydrocarbon from a hydrocarbon reservoir. After the well is filled with the fluid, the volume of

the fluid entering the first end of the wellbore may be substantially equal to a volume of the fluid exiting the second end of the wellbore. After the fluid has passed through the wellbore, the fluid may be free of heavy hydrocarbon from the heavy hydrocarbon reservoir.

5 The temperature of the heating fluid exiting the reservoir may be in a range from 350°C to 580°C (e.g., from 400°C to 530°C, or from 450°C to 500°C). At least a portion of the hydrocarbon material in the hydrocarbon reservoir, may be heated (using the heating fluid) to a temperature ranging from 100°C to 240°C (e.g., from 150°C to 230°C, or from 200°C to 220°C). In some embodiments, some or all of the hydrocarbons may be transformed into lighter hydrocarbons, water, and gas during heating. In some embodiments, temperature within
10 at least a portion of the hydrocarbon reservoir can be increased to a pyrolyzation temperature (e.g., to a temperature of between 250°C and 400°C).

Methods of producing a heavy hydrocarbon from a hydrocarbon reservoir are also disclosed herein. The method can include heating a portion of the hydrocarbon reservoir by passing a heating fluid through a fully enclosed well in the hydrocarbon reservoir; and
15 extracting the heavy hydrocarbon from the hydrocarbon reservoir. In some embodiments, extracting the heavy hydrocarbon from the hydrocarbon reservoir can include perforating the fully enclosed well to extract the heavy hydrocarbon after heating the portion of the hydrocarbon reservoir. In some embodiments, the hydrocarbon reservoir can include one or more additional wells for extraction of the heavy hydrocarbon after heating the portion of the
20 hydrocarbon reservoir.

The method of producing the heavy hydrocarbon can further include contacting the heavy hydrocarbon with a material to displace the heavy hydrocarbon from the hydrocarbon reservoir. The material can be selected from water, an alcohol, a solvent, a surfactant, a hydrocarbon, an alkali agent, a polymer, carbon disulfide, carbon dioxide, or a combination
25 thereof.

DESCRIPTION OF DRAWINGS

Figure 1 shows a sequence of a pump **10**, condenser **20**, steam generator **30**, and compressor **40**. The compressed steam **50** is piped through a closed loop **55** through a heavy oil reservoir **60**, thereby heating up surrounding material in the reservoir **60** to a viscosity
30 suitable for removing as product **70** through pipe **75**.

Figure 2 is a schematic block diagram illustrating a portion of the earth including an oil shale reservoir, and further illustrating an example heating system for heating the oil shale reservoir.

DETAILED DESCRIPTION

5 Provided herein are systems and methods for treating a subsurface formation. In some embodiments, the disclosure provides an *in situ* conversion system for producing hydrocarbons from a subsurface formation, including: a plurality of wellbores in the formation; piping positioned in at least one of the wellbores and a fluid circulation system coupled to the piping, wherein the fluid circulation system is configured to circulate a heat transfer fluid through at least a portion of the piping to form at least one heated portion of the formation. There may also be an electrical power supply, configured to provide electrical current to at least a portion of the piping located below an overburden in the formation to resistively heat at least a portion of the piping, and wherein heat transfers from the piping to the formation.

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

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

25 A “formation” can include one or more hydrocarbon containing layers, one or more non-hydrocarbon layers, an overburden, and/or an underburden. The “overburden” and/or the underburden” include one or more different types of impermeable materials. For example, overburden and/or underburden may include rock, shale, mudstone, or wet/tight carbonate. In some embodiments of *in situ* conversion processes, the overburden and/or the underburden may include a hydrocarbon containing layer or hydrocarbon containing layers that are relatively

impermeable and are not subjected to temperatures during *in situ* conversion processing that result in significant characteristic changes of the hydrocarbon containing layers of the overburden and/or the underburden. For example, the underburden may contain shale or mudstone, but the underburden is not allowed to heat to pyrolysis temperatures during the *in situ* conversion process. In some cases, the overburden and/or the underburden may be somewhat permeable.

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

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

Heavy hydrocarbons may be found in a relatively permeable formation. The relatively permeable formation may include heavy hydrocarbons entrained in, for example, sand or carbonate. “Relatively permeable” is defined, with respect to formations or portions thereof, as an average permeability of 10 millidarcy or more (for example, 10 or 100 millidarcy).

In some cases, a portion or all of a hydrocarbon portion of a relatively permeable formation may be predominantly heavy hydrocarbons and/or tar with no supporting mineral grain framework and only floating (or no) mineral matter (for example, asphalt lakes).

Certain types of formations that include heavy hydrocarbons may also be, but are not limited to, natural mineral waxes, or natural asphaltites. “Natural mineral waxes” typically occur in substantially tubular veins that may be several meters wide, several kilometers long, and hundreds of meters deep. “Natural asphaltites” include solid hydrocarbons of an aromatic composition and typically occur in large veins. *In situ* recovery of hydrocarbons from

formations such as natural mineral waxes and natural asphaltites may include melting to form liquid hydrocarbons and/or solution mining of hydrocarbons from the formations.

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

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

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

15 “Triad” refers to a group of three items (for example, heaters, wellbores, or other objects) coupled together. “Orifices” refer to openings, such as openings in conduits, having a wide variety of sizes and cross-sectional shapes including, but not limited to, circles, ovals, squares.

“Upgrade” refers to increasing the quality of hydrocarbons. For example, upgrading heavy hydrocarbons may result in an increase in the API gravity of the heavy hydrocarbons.

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

25 The term “polymer” refers to a molecule having a structure that essentially includes the multiple repetitions of units derived, actually or conceptually, from molecules of low relative molecular mass. In some embodiments, the polymer is an oligomer.

Methods

30 Methods of heating a hydrocarbon containing formation, particularly a hydrocarbon reservoir comprised of heavy oil are provided herein. As the formation is heated, the viscosity of the hydrocarbon may be reduced to a point at which the fluids in the reservoir become mobile and flow at an economic rate.

The methods disclosed herein can include forming a fully enclosed circulation system in at least a portion of a hydrocarbon reservoir. The fully enclosed circulation system provides passage of the heating fluid through the hydrocarbon reservoir without being injected directly into the formation. A possible benefit of using the fully enclosed wellbore is that there is little concern about multi-phase flow.

The circulation system used in the hydrocarbon reservoir can be defined by a wellbore or a conduit. A typical wellbore includes perforations that enable fluid to flow between the wellbore and an underground reservoir. However, the fully enclosed wellbore disclosed herein is substantially non-perforated to prevent communication of the heating fluid into the hydrocarbon reservoir, and of the heavy hydrocarbon, or other constituents of the portion of the reservoir into the heating fluid. In some embodiments, the fully enclosed wellbore can comprise a conduit. For example, the wellbore can include a drill pipe, a wired drill pipe, a tube, or a casing. In some examples, the wellbore can include a tubular member defining an internal flow channel that provides thermal communication with the internal flow channel and the hydrocarbon reservoir. Optionally, the conduit can be equipped with electrical cables and heaters that can be used to heat the hydrocarbon reservoir.

The fully enclosed wellbore can have any suitable shape for efficient heat transfer to the heavy oil in the reservoir. In some embodiments, the wellbore can be a U-shaped wellbore. In some embodiments, the wellbore can be a network of connected wellbores.

The circulation system in the hydrocarbon reservoir can be a closed loop circulation system. The term "closed loop" as used herein refers to a circulation system that re-circulates the same fluid and have no need of a well or a place to discharge the fluid. The closed loop circulation system can circulate fluids continuously between the active and passive spaces of the circulation system without being removed (e.g., by or to an external pumping mechanism). The closed loop circulation system provides that after the well is filled with a heating fluid, the volume of the fluid entering the first end of the well is substantially equal to a volume of fluid exiting the second end of the well. Operational expenditures may be minimized using the closed-loop system. For example, if steam, for example, is used in the closed loop, there is no water lost, and there is little concern about multi-phase flow.

In some embodiments, the wellbore can be coupled to wellheads, which can then form the closed loop circulation system. For example, the wellbore can include a first and a second end. The first end and the second end of the wellbore are located above the hydrocarbon

reservoir. The first end of the wellbore can be coupled to a first wellhead and the second end of the wellbore can be coupled to a second wellhead. However, the number of wellheads coupled to a wellbore (or the number of wellbore coupled to a wellhead) are not limited. In a further embodiment, the hydrocarbon reservoir can include multiple fully enclosed wellbores.

5 The method further include passing a heating fluid through the wellbore to heat the heavy oil. The fluid circulation system can absorb heat or reject heat into the surrounding reservoir. The heating fluid can be any fluid that allows for the greatest heat transfer to the reservoir fluids. For example, the heating fluid can be a liquid, a gas, an emulsion, a slurry, a stream of solid particles that have flow characteristics, or a mixed phase fluid. In some embodiments, the
10 heating fluid can include steam. Steam is chemically stable at the required temperatures and pressures and has a relatively high molecular weight that results in a high volumetric heat capacity. The steam used in the wellbore can be derived from seawater, or fresh water from an aquifer, river or lake. In some embodiments, the steam can be derived from hard brine water or soft brine water.

15 In some embodiments, the heating fluid can include a hydrocarbon supplied from a hydrocarbon well after extraction of the hydrocarbon from a hydrocarbon reservoir. Other suitable heating fluids can include carbon dioxide (CO₂), air, helium and/or nitrogen.

The heating fluid can be delivered to the wellbore by pumping the heating fluid into the wellhead and through the first end of the wellbore. The heating fluid continues through the
20 wellbore and through a lateral segment of the wellbore before completing the cycle through the second end of the wellbore. Any suitable mechanism for pumping the heating fluid can be utilized that allows the fluid to go into the wellbore such as those typically used in hydraulic fracturing.

The temperature of the heating fluid can be greater than the temperature of the heavy
25 hydrocarbon in the heavy hydrocarbon reservoir. In some embodiments, the heating fluid has a temperature of from 700°C to 920°C, from 770°C to 870°C, or from 800°C to 850°C. The temperature of the heating fluid exiting the reservoir may be in a range from 350°C to 580°C, from 400°C to 530°C, or from 450°C to 500°C. A heat supply, such as a heater, may be placed inside or outside the wellbores to heat the heating fluid and as such the hydrocarbon reservoir.
30 The heat supply can be in the form of a piping that is positioned in the U-shaped wellbore to form a U-shaped heater. U.S. Patent No. 7,575,052 describes downhole heaters that can be used in the methods described herein, the entirety of which is incorporated by reference.

At least a portion of the hydrocarbon material in the hydrocarbon reservoir, may be heated (using the heating fluid) to a temperature ranging from 100°C to 240°C, from 150°C to 230°C, or from 200°C to 220°C. During heating, hydrocarbons may be transformed into lighter hydrocarbons, water, and gas. In some embodiments, temperature within at least a portion of the hydrocarbon reservoir can be increased to a pyrolyzation temperature (for example, between 250°C and 400°C).

FIG. 2 is schematic block diagram illustrating a portion of the earth **50** including a reservoir comprising heavy hydrocarbon **80**, and further illustrating an example heating system **100** for heating the heavy hydrocarbon reservoir **80**. The portion of the earth **50** includes a surface **52** and a subsurface portion **54**. The portion of the earth **50** may include land, or land and sea, for example. **80** is located in the subsurface portion **54**, and includes heavy hydrocarbon **82**. Typically the heavy hydrocarbon reservoir **80** is naturally occurring, and is located some distance below the surface **52**.

In this example, the heating system **100** includes a well **102** having a wellbore **104**. The wellbore **104** can be formed by drilling through the portion of the earth **50**, for example. The wellbore **104** typically includes a first end **106** and a second end **108**, and defines a passageway between the first end **106** and the second end **108**. In some embodiments, the well **102** also includes well heads. For example, the first end **106** of the wellbore **104** is coupled to a well head **110**, and the second end **108** of the wellbore **104** is coupled to the well head **112**.

To heat the heavy hydrocarbon **82** within the heavy hydrocarbon reservoir **80**, a fluid **114**, e.g. steam, is passed through the well **100**. As one example, fluid **114** is pumped into the well head **110** and through the first end **106** of the wellbore **104**. The fluid **114** continues through the wellbore **104** and into the heavy hydrocarbon reservoir **80**. The fluid **114** has a temperature that is greater than a temperature of the heavy hydrocarbon reservoir. Therefore, heat from the fluid **114** is transferred into the heavy hydrocarbon reservoir, forming a heated portion **120** adjacent the wellbore **104**. The fluid **114** proceeds along the wellbore **104** to the second end **108** where the fluid **114** exits the wellbore through the well head **112**.

In order to heat a larger portion of the hydrocarbon reservoir, the heating system can include two or more adjacent wells. A heating fluid is supplied through the wells, which heats the heavy hydrocarbon adjacent to the wells generating a larger heated portion.

Once heating has been completed, the produced hydrocarbon can be extracted. The hydrocarbon reservoir can include multiple wellbores such that at least one of the wellbore can

be used for heating while another of the wellbore can be used for production (extraction) of the produced hydrocarbon. The multiple wellbores can be operated simultaneously, for example, to heat the heavy hydrocarbon through a first well at the same time that the heavy hydrocarbon is being produced from the reservoir through a second well. Alternately, after the hydrocarbon reservoir is heated, the fully enclosed wellbore can be perforated and converted into a portion of a production system. In this example, the wellbore is perforated to permit extraction of the heavy hydrocarbon.

A fluid may be introduced into the hydrocarbon reservoir before and/or after the heat treatment of the reservoir to enhance recovery of the hydrocarbon material. “Enhanced recovery” or “enhanced oil recovery” refers to techniques for increasing the amount of hydrocarbon that may be extracted from a formation (e.g., an oil reservoir). Examples of enhanced oil recovery operations include, for example, miscible gas injection (which includes, for example, carbon dioxide flooding), chemical injection (sometimes referred to as chemical enhanced oil recovery (CEOR), and which includes, for example, polymer flooding, alkaline flooding, surfactant flooding, conformance control operations, as well as combinations thereof such as alkaline-polymer flooding or alkaline-surfactant-polymer flooding), microbial injection, and thermal recovery (which includes, for example, cyclic steam, steam flooding, and fire flooding). In some embodiments, the enhanced oil recovery operation can include a polymer (P) flooding operation, an alkaline-polymer (AP) flooding operation, a surfactant-polymer (SP) flooding operation, an alkaline-surfactant-polymer (ASP) flooding operation, a conformance control operation, or any combination thereof. The terms “operation” and “application” may be used interchangeably herein, as in enhanced oil recovery operations or enhanced oil recovery applications. The mixture formed may have a reduced viscosity compared to the initial viscosity of the fluids in the formation. The mixture may flow and/or be mobilized towards production wells in the formation.

In some embodiments, the method can include contacting the hydrocarbon material in the hydrocarbon reservoir with a fluid such as water, an alcohol, a solvent, a surfactant, a hydrocarbon, alkaline water solutions (for example, sodium carbonate solutions), caustic, polymers, carbon disulfide, carbon dioxide, or a combination thereof.

In some embodiments, the method can include contacting the hydrocarbon material with a surfactant. A surfactant, as used herein, is a compound within the aqueous composition that functions as a surface active agent when the aqueous composition is in contact with a crude oil

(e.g., an unrefined petroleum). The surfactant can act to lower the interfacial tension and/or surface tension of the unrefined petroleum. The surfactant can comprise an anionic surfactant, a non-ionic surfactant, a zwitterionic surfactant, a cationic surfactant, or a combination thereof. The surfactant can be any appropriate surfactant useful in the field of enhanced oil recovery. For example, in some embodiments, the surfactant can comprise an internal olefin sulfonate (IOS), an alpha olefin sulfonate (AOS), an alkyl aryl sulfonate (ARS), an alkane sulfonate, a petroleum sulfonate, an alkyl diphenyl oxide (di)sulfonate, an alcohol sulfate, an alkoxy sulfate, an alkoxy sulfonate, an alcohol phosphate, an alkoxy phosphate, a sulfosuccinate ester, an alcohol ethoxylate, an alkyl phenol ethoxylate, a quaternary ammonium salt, a betaine or sultaine. The surfactant as provided herein, can also be a soap.

Suitable surfactants are disclosed, for example, in U.S. Patent Nos. 3,811,504, 3,811,505, 3,811,507, 3,890,239, 4,463,806, 6,022,843, 6,225,267, and 7,629,299; International Patent Application Publication Nos. WO/2008/079855, WO/2012/027757 and WO 2011/094442; as well as U.S. Patent Application Publication Nos. 2005/0199395, 2006/0185845, 2006/018486, 2009/0270281, 2011/0046024, 2011/0100402, 2011/0190175, 2007/0191633, 2010/004843, 2011/0201531, 2011/0190174, 2011/0071057, 2011/0059873, 2011/0059872, 2011/0048721, 2010/0319920, 2010/0292110, and 2013/0281327, all of which are incorporated herein by reference in their entirety. Additional suitable surfactants are surfactants known to be used in enhanced oil recovery methods, including those discussed in D. B. Levitt, A. C. Jackson, L. Britton and G. A. Pope, "Identification and Evaluation of High-Performance EOR Surfactants," SPE IX89, conference contribution for the SPE Symposium on Improved Oil Recovery Annual Meeting, Tulsa, Okla., Apr. 24-26, 2006. In some embodiments, the total surfactant concentration can be from about 0.05% w/w to about 10% w/w.

In some embodiments, the method can include contacting the hydrocarbon material with a viscosity enhancing water-soluble polymer. The water-soluble polymer may be a biopolymer such as xanthan gum or scleroglucan, a synthetic polymer such as polyacrylamide, hydrolyzed polyacrylamide or co-polymers of acrylamide and acrylic acid, 2-acrylamido 2-methyl propane sulfonate or *N*-vinyl pyrrolidone, a synthetic polymer such as polyethylene oxide, or any other high molecular weight polymer soluble in water or brine. In some embodiments, the polymer is polyacrylamide (PAM), partially hydrolyzed polyacrylamides (HPAM), and copolymers of 2-acrylamido-2-methylpropane sulfonic acid or sodium salt or mixtures thereof,

and polyacrylamide (PAM) commonly referred to as AMPS copolymer and mixtures of the copolymers thereof. In one embodiment, the viscosity enhancing water-soluble polymer is polyacrylamide or a co-polymer of polyacrylamide. Examples of commercially available polymers for use herein include Florpaam 3330S and Florpaam 3360S. The viscosity enhancing water-soluble polymer can be used in the range of about 500 to about 5000 ppm concentration, such as from about 1000 to 2000 ppm (e.g., in order to match or exceed the reservoir oil viscosity under the reservoir conditions of temperature and pressure).

In some embodiments, the method can include contacting the hydrocarbon material with an alkali agent. An alkali agent as provided herein can be a basic, ionic salt of an alkali metal (e.g., lithium, sodium, potassium) or alkaline earth metal element (e.g., magnesium, calcium, barium, radium). Examples of suitable alkali agents include, for example, NaOH, KOH, LiOH, Na₂CO₃, NaHCO₃, Na-metaborate, Na silicate, Na orthosilicate, Na acetate or NH₄OH. The alkali agent can be present in the hydrocarbon reservoir at a concentration from 0.1% w/w to 10% w/w (e.g., from 0.1% w/w to 5% w/w). In some embodiments, the alkali agent can be present in an effective amount to afford a pH of from 8 to 12 (e.g., 10 to 12).

In some embodiments, the method can include contacting the hydrocarbon material with a co-solvent. The co-solvent can be an alcohol, alcohol ethoxylate, glycol ether, glycols, or glycerol. In embodiments, the hydrocarbon reservoir includes a plurality of different additional co-solvents. Suitable co-solvents include alcohols (e.g., C₁-C₆ alcohols and C₁-C₄ alcohols), alkyl alkoxy alcohols (e.g., C₁-C₆ alkoxy alcohols and C₁-C₄ alkoxy alcohols), and phenyl alkoxy alcohols. The alkyl alkoxy alcohols or phenyl alkoxy alcohols provided herein have a hydrophobic portion (alkyl or aryl chain), a hydrophilic portion (e.g., an alcohol) and optionally an alkoxy (ethoxylate or propoxylate) portion. Thus, the co-solvent can be an alcohol, alkoxy alcohol, glycol ether, glycol or glycerol. Suitable co-solvents are known in the art, and include, for example, co-solvents described in U.S. Patent Application Publication No. 2013/0281327 which is hereby incorporated herein in its entirety. The co-solvent can be used in combination with a surfactant.

In some embodiments, the method can include contacting the hydrocarbon material with a gas. For instance, the gas may be combined with the hydrocarbon composition to reduce its mobility by decreasing the liquid flow in the pores of the solid material (e.g., rock). In some embodiments, the gas may be supercritical carbon dioxide, nitrogen, natural gas or mixtures of these and other gases.

The compositions and methods of the appended claims are not limited in scope by the specific compositions and methods described herein, which are intended as illustrations of a few aspects of the claims. Any compositions and methods that are functionally equivalent are intended to fall within the scope of the claims. Various modifications of the compositions and methods in addition to those shown and described herein are intended to fall within the scope of the appended claims. Further, while only certain representative compositions and method steps disclosed herein are specifically described, other combinations of the compositions and method steps also are intended to fall within the scope of the appended claims, even if not specifically recited. Thus, a combination of steps, elements, components, or constituents may be explicitly mentioned herein or less, however, other combinations of steps, elements, components, and constituents are included, even though not explicitly stated.

The term “comprising” and variations thereof as used herein is used synonymously with the term “including” and variations thereof and are open, non-limiting terms. Although the terms “comprising” and “including” have been used herein to describe various embodiments, the terms “consisting essentially of” and “consisting of” can be used in place of “comprising” and “including” to provide for more specific embodiments of the disclosure and are also disclosed. Other than where noted, all numbers expressing geometries, dimensions, and so forth used in the specification and claims are to be understood at the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, to be construed in light of the number of significant digits and ordinary rounding approaches.

It is understood that when combinations, subsets, groups, etc. of elements are disclosed (e.g., combinations of components in a composition, or combinations of steps in a method), that while specific reference of each of the various individual and collective combinations and permutations of these elements may not be explicitly disclosed, each is specifically contemplated and described herein. By way of example, if a composition is described herein as including a component of type A, a component of type B, a component of type C, or combination thereof, it is understood that this phrase describes all of the various individual and collective combinations and permutations of these components. For example, in some embodiments, the composition described by this phrase could include only a component of type A. In some embodiments, the composition described by this phrase could include only a component of type B. In some embodiments, the composition described by this phrase could include only a component of type C. In some embodiments, the composition described by this

phrase could include a component of type A and a component of type B. In some
embodiments, the composition described by this phrase could include a component of type A
and a component of type C. In some embodiments, the composition described by this phrase
could include a component of type B and a component of type C. In some embodiments, the
5 composition described by this phrase could include a component of type A, a component of
type B, and a component of type C. In some embodiments, the composition described by this
phrase could include two or more components of type A (e.g., A1 and A2). In some
embodiments, the composition described by this phrase could include two or more components
of type B (e.g., B1 and B2). In some embodiments, the composition described by this phrase
10 could include two or more components of type C (e.g., C1 and C2). In some embodiments, the
composition described by this phrase could include two or more of a first component (e.g., two
or more components of type A (A1 and A2)), optionally one or more of a second component
(e.g., optionally one or more components of type B), and optionally one or more of a second
component (e.g., optionally one or more components of type C). In some embodiments, the
15 composition described by this phrase could include two or more of a first component (e.g., two
or more components of type B (B1 and B2)), optionally one or more of a second component
(e.g., optionally one or more components of type A), and optionally one or more of a second
component (e.g., optionally one or more components of type C). In some embodiments, the
composition described by this phrase could include two or more of a first component (e.g., two
20 or more components of type C (C1 and C2)), optionally one or more of a second component
(e.g., optionally one or more components of type A), and optionally one or more of a second
component (e.g., optionally one or more components of type B).

Unless defined otherwise, all technical and scientific terms used herein have the same
meanings as commonly understood by one of skill in the art to which the disclosure belongs.
25 Publications cited herein and the materials for which they are cited are specifically incorporated
by reference.

WHAT IS CLAIMED IS:

1. A method of heating a heavy hydrocarbon, the method comprising:
forming a fully enclosed well through a portion of a heavy hydrocarbon reservoir, the reservoir containing a heavy hydrocarbon; and
passing a heating fluid through the well to heat the heavy hydrocarbon in the portion of the heavy hydrocarbon reservoir.
2. The method of claim 1, wherein a temperature of the heating fluid is greater than a temperature of the heavy hydrocarbon in the heavy hydrocarbon reservoir.
3. The method of claim 2, wherein the temperature of the heating fluid is an initial temperature of the heating fluid before the heating fluid passes through the portion of the heavy hydrocarbon reservoir.
4. The method of any one of claims 1-3, wherein the well includes first and second ends, and wherein the first end of the well is coupled to a first wellhead and wherein the second end of the well is coupled to a second wellhead.
5. The method of any one of claims 1-4, wherein after the well is filled with the fluid, a volume of the fluid entering the first end of the well is substantially equal to a volume of the fluid exiting the second end of the well.
6. The method of any one of claims 1-5, wherein after the fluid has passed through the well, the fluid is free of heavy hydrocarbon from the heavy hydrocarbon reservoir.
7. The method of any one of claims 1-6, wherein the heating fluid is steam.
8. The method of any one of claims 1-6, wherein the heating fluid is hydrocarbon supplied from a hydrocarbon well after extraction of the hydrocarbon from a hydrocarbon reservoir.
9. The method of any one of claims 1-8, wherein the heavy hydrocarbon has an API gravity of less than 20°.

10. The method of any one of claims 1-9, wherein the heavy hydrocarbon has an API gravity of less than 10°.
11. The method of any one of claims 1-10, wherein the heavy hydrocarbon has a viscosity of at least 100 centipoise at 15°C.
12. The method of any one of claims 1-11, wherein the heavy hydrocarbon has a density of at least 1,000 kg/m³
13. The method of any one of claims 1-12, wherein the portion of the reservoir has a permeability of 10 millidarcy or more.
14. The method of any one of claims 1-13, wherein the heating fluid has a temperature of from 700°C to 920°C.
15. The method of any one of claims 1-14, wherein the heavy hydrocarbon is heated to a temperature of from 100°C to 240°C.
16. A method of producing a heavy hydrocarbon from a hydrocarbon reservoir, the method comprising:
 - heating a portion of the hydrocarbon reservoir by passing a heating fluid through a fully enclosed well in the hydrocarbon reservoir; and
 - extracting the heavy hydrocarbon from the hydrocarbon reservoir.
17. The method of claim 16, further comprising perforating the well after heating the portion of the hydrocarbon reservoir to extract the heavy hydrocarbon.
18. The method of claim 16 or 17, further comprising forming an additional well to extract the heavy hydrocarbon.

19. The method of any one of claims 16-18, further comprising contacting the heavy hydrocarbon with a material to displace the heavy hydrocarbon from the hydrocarbon reservoir.

20. The method of claim 19, wherein the material is selected from water, an alcohol, a solvent, a co-solvent, a surfactant, a hydrocarbon, an alkali agent, a polymer, carbon disulfide, carbon dioxide, nitrogen, natural gas, or a combination thereof.

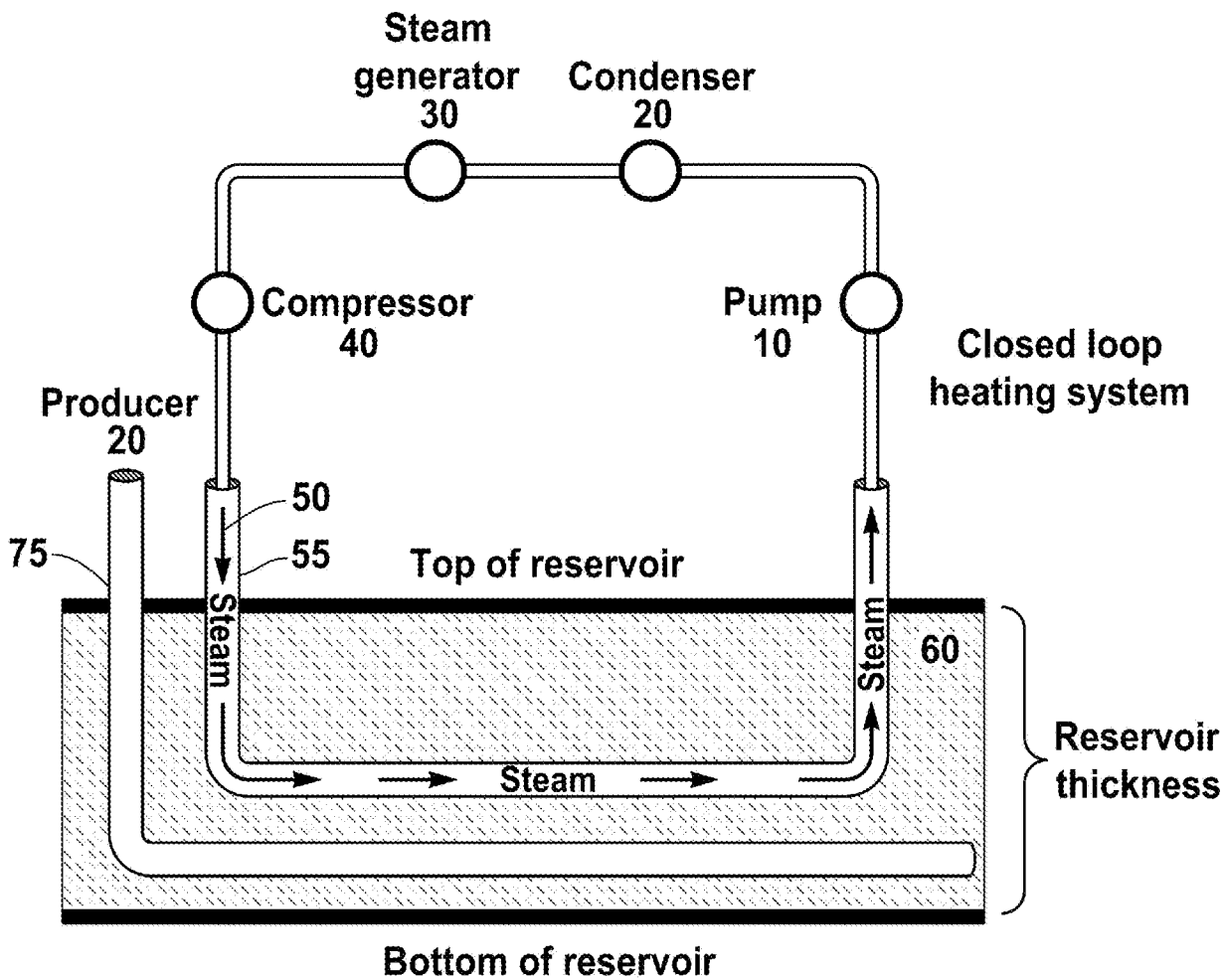


FIGURE 1

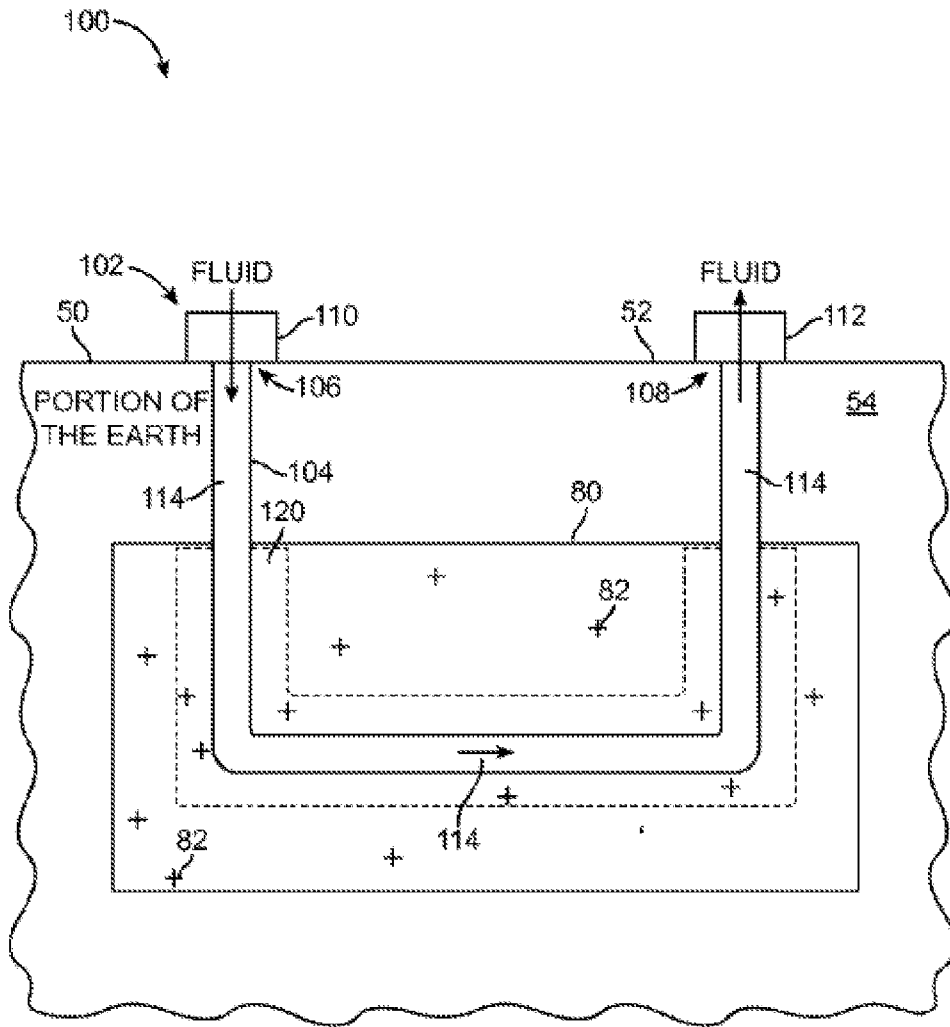


FIGURE 2

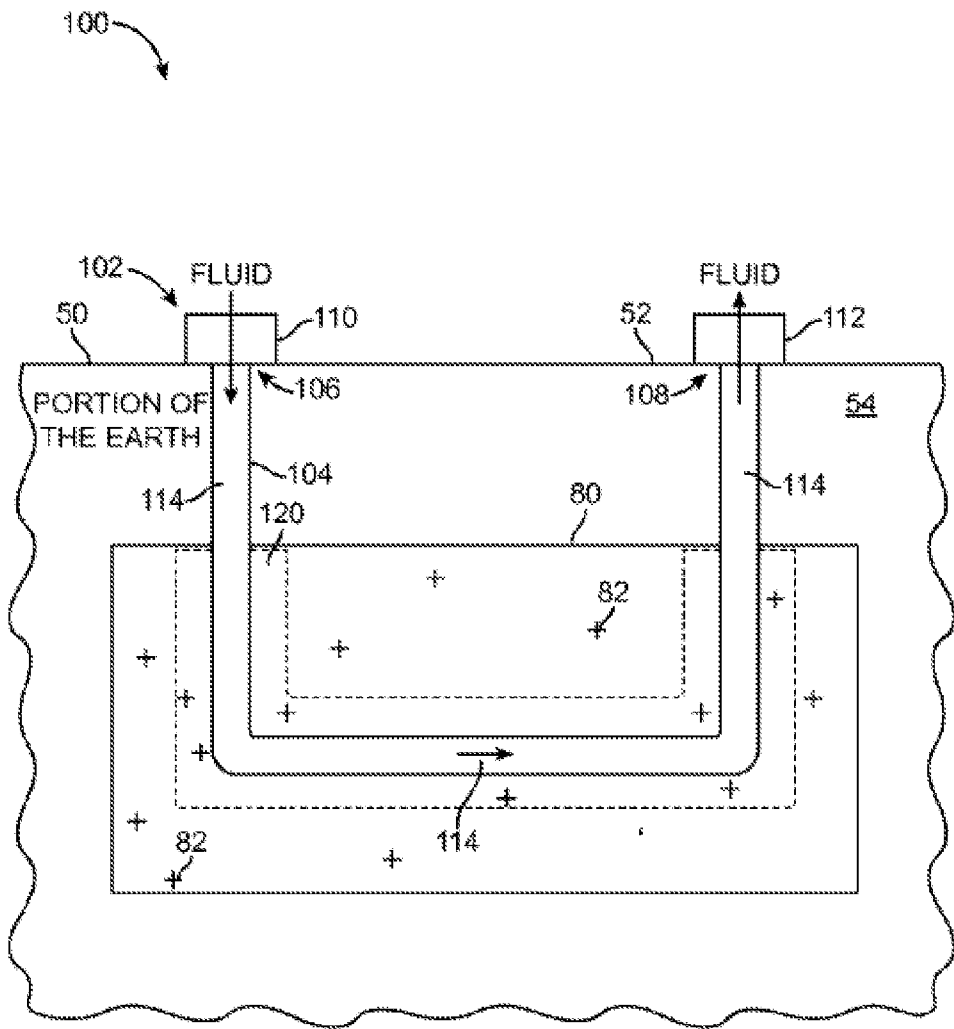


FIGURE 2