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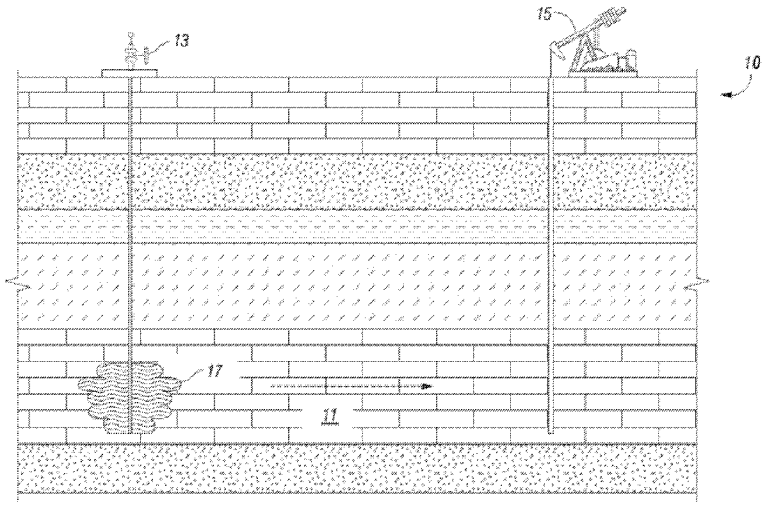

FIG. 1

(57) Abstract: A system and method is disclosed for enhancing the distribution of an enhanced oil recovery fluid utilizing electrokinetic-induced migration for enhancing oil recovery from a subterranean reservoir. An enhanced oil recovery fluid is injected into the hydrocarbon bearing zone through the injection well. An electric field is generated through at least a portion of the hydrocarbon bearing zone to induce electrokinetic migration of the enhanced oil recovery fluid. Electrokinetic induced migration allows for the enhanced oil recovery fluid to contact portions of the reservoir that previously were unswept, which as a result enhances recovery of hydrocarbons through the production well.

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SYSTEM AND METHOD FOR ENHANCING OIL RECOVERY FROM A SUBTERRANEAN RESERVOIR

CROSS-REFERENCE TO A RELATED APPLICATION

[001] The present application for patent claims the benefit of United States Provisional Application bearing Serial No. 61/425,517, filed on December 21, 2010, which is incorporated by reference in its entirety.

TECHNICAL FIELD

[002] The present invention generally relates to a system and method for enhancing oil recovery from a subterranean reservoir, and more particularly, to a system and method utilizing electrokinetic-induced migration to enhance the distribution of an enhanced oil recovery fluid within a subterranean reservoir.

BACKGROUND

[003] Reservoir systems, such as petroleum reservoirs, typically contain fluids including water and a mixture of hydrocarbons such as oil and gas. Primary, secondary, and tertiary recovery processes can be utilized to produce the hydrocarbons from the reservoir.

[004] In a primary recovery process, hydrocarbons are displaced from a reservoir due to the high natural differential pressure between the reservoir and the bottomhole pressure within a wellbore. The reservoir's energy and natural forces drive the hydrocarbons contained in the reservoir into the production well and up to the surface. Artificial lift systems, such as sucker rod pumps, electrical submersible pumps or gas-lift systems, are often implemented in the primary production stage to reduce the bottomhole pressure within the well. Such systems increase the differential pressure between the reservoir and the wellbore intake; thus, increasing hydrocarbon production. However, even with the use of such artificial lift systems only a small fraction of the original-oil-in-place (OOIP) is typically

recovered in a primary recovery process. This is the case because the reservoir pressure and the differential pressure between the reservoir and the wellbore intake declines overtime due to production. For example, typically only about 10-20% of the OOIP can be produced before primary recovery reaches its limit - either when the reservoir pressure is too low that the production rates are not economical, or when the proportions of gas or water in the production stream are too high.

[005] To address the declining recoveries and increase the production life of the reservoir, secondary recovery processes can be used. Typically in these processes, fluids such as water or gas are injected into the reservoir to maintain reservoir pressure and drive the hydrocarbons to production wells. Secondary recovery processes have already converted billions of barrels of proven oil resources to reserves, and typically produce an additional 10-30% of OOIP to that produced during primary recovery. Additional actions such as optimizing rate allocation, mechanical and chemical conformance control, infill drilling, well conversion, pattern realignment, or a combination thereof, can also be taken to improve the sweep efficiency in these flooding processes.

[006] Despite these efforts, a significant amount of the OOIP still remains trapped in the reservoir as conventional oil recovery methods (primary and secondary) typically only extract up to about half the oil present in a reservoir. As oil reservoirs age, oil recovery becomes increasingly difficult. The hydraulic injection of fluid results in channeling of the fluid through higher permeability features, such as fractures or coarser lenses present within the reservoir, leaving other zones of the reservoir unswept. Furthermore, the unrecovered oil in the swept zones is typically in the form of discontinuous blobs and globules trapped by capillary pressure within the porous framework of the reservoir soil and rock. Tertiary recovery processes such as chemical flooding (e.g., surfactant, solvent or oxidant injection),

gas miscible displacement (e.g., carbon dioxide or hydrocarbon injection), thermal recovery (e.g., steam injection or in-situ combustion), microbial flooding, or a combination thereof, have been used in attempt to further increase recovery from these depleted reservoirs.

[007] Chemical flooding, which as used herein refers to an injection process using a chemical or mixture of chemicals to enhance oil recovery typically by reducing interfacial tensions and fluid viscosity in the reservoir, currently contributes to a small portion of tertiary production. Despite recent advances in generating new chemical formulations that have shown to successfully release trapped oil globules from the porous framework of the reservoir, good contact between the injected chemical and oil is typically limited to preferential flow channels due to channeling of flow through high conductivity zones. Accordingly, the injected chemicals typically do not contact the majority of trapped oil in the reservoir.

[008] Polymer injections can supplement chemical floods (or water floods) by acting as a viscosity modifier, thereby reducing channeling and helping to mobilize or drive the oil to a production well. In some embodiments, the polymer can be used to block the high conductivity zones or permeability features, thereby diverting the injected fluids or chemicals into areas that have not previously been subjected to flow. However, the benefits of polymer injection are typically minimal because the radius of influence around a well where the polymer can move is limited leaving the flow dynamics throughout the majority of the reservoir unchanged. Therefore, the increased oil recovery resulting from a chemical flood has typically been low, such as less than about 1 percent. Due to the cost of injecting chemicals, this low increase in oil recovery is rarely cost effective even though a slight increase in oil recovery efficiency producing an additional 1 percent of residual oil can represent billions of dollars.

[009] A main limitation of water or chemical floods is that conventional well-injection techniques do not allow for wide-spread contact between the injected fluid and the trapped oil. A way to evenly distribute the injected fluid throughout a larger portion of the reservoir is needed for enhancing oil recovery.

SUMMARY

[010] A method is disclosed for enhancing hydrocarbon recovery in subterranean reservoirs. An injection well and a production well extend into a hydrocarbon bearing zone of the subterranean reservoir and are in fluid communication therewith. The method includes injecting an enhanced oil recovery fluid into the hydrocarbon bearing zone through the injection well. An electric field is generated through at least a portion of the hydrocarbon bearing zone to induce electrokinetic migration of the enhanced oil recovery fluid. Hydrocarbons from the hydrocarbon bearing zone of the subterranean reservoir are recovered through the production well.

[011] In one or more embodiments, the electric field is generated by emitting a direct current between a pair of electrodes having opposite charges and being spaced apart from one another within the hydrocarbon bearing zone. In one or more embodiments, the electric field is generated by emitting a direct current between a first electrode coupled to the injection well and a second electrode coupled to the production well. In one or more embodiments, the electric field is generated by emitting a direct current less than about 50 volts per meter between a pair of electrodes. In one or more embodiments, the direct current is periodically pulsed. In one or more embodiments, the polarity of the pair of electrodes is periodically reversed.

[012] In one or more embodiments, the electric field is generated by emitting a direct current between a plurality of electrodes interspersed within the hydrocarbon bearing zone.

The direct current emitted between one or more of the plurality of electrodes can be adjusted such that the enhanced oil recovery fluid migrates to unswept areas of the hydrocarbon bearing zone.

[013] In one or more embodiments, the enhanced oil recovery fluid comprises a polar fluid. In one or more embodiments, the enhanced oil recovery fluid has a net total charge. In one or more embodiments, the enhanced oil recovery fluid comprises water. In one or more embodiments, the enhanced oil recovery fluid comprises a surfactant. In one or more embodiments, the enhanced oil recovery fluid comprises an oxidant. In one or more embodiments, the enhanced oil recovery fluid alters a physical property of a formation matrix of the hydrocarbon bearing zone.

[014] According to another aspect of the present invention, a method is disclosed for enhancing hydrocarbon recovery in subterranean reservoirs. The method includes providing an injection well and a production well that extend into and are in fluid communication with a hydrocarbon bearing zone of a subterranean reservoir and providing a pair of electrodes having opposite charges and being spaced apart from one another within the hydrocarbon bearing zone. An enhanced oil recovery fluid is injected into the hydrocarbon bearing zone through the injection well. A direct current is emitted between the pair of electrodes to induce electrokinetic migration of the enhanced oil recovery fluid. Hydrocarbons are recovered from the hydrocarbon bearing zone of the subterranean reservoir through the production well.

[015] In one or more embodiments, the direct current is less than about 50 volts per meter. In one or more embodiments, the direct current is periodically pulsed. In one or more embodiments, the polarity of the pair of electrodes is periodically reversed.

[016] In one or more embodiments, an electrode of the pair of electrodes is coupled to the injection well. In one or more embodiments, an electrode of the pair of electrodes is coupled to the production well.

[017] In one or more embodiments, the enhanced oil recovery fluid comprises water. In one or more embodiments, the enhanced oil recovery fluid comprises a surfactant. In one or more embodiments, the enhanced oil recovery fluid comprises an oxidant. In one or more embodiments, the enhanced oil recovery fluid alters a physical property of a formation matrix of the hydrocarbon bearing zone.

[018] According to another aspect of the present invention, a method is disclosed for enhancing hydrocarbon recovery in subterranean reservoirs. The method includes providing an injection well and a production well that extend into a hydrocarbon bearing zone of a subterranean reservoir and are in fluid communication therewith. A plurality of electrodes are interspersed within the hydrocarbon bearing zone of a subterranean reservoir. An enhanced oil recovery fluid is injected into the hydrocarbon bearing zone through the injection well. A direct current is emitted between the plurality of electrodes to induce electrokinetic migration of the enhanced oil recovery fluid. Hydrocarbons from the hydrocarbon bearing zone of the subterranean reservoir are recovered through the production well.

[019] In one or more embodiments, the direct current emitted between one or more of the plurality of electrodes is adjusted such that the enhanced oil recovery fluid migrates to unswept areas of the hydrocarbon bearing zone.

BRIEF DESCRIPTION OF THE DRAWINGS

[020] Figure 1 is a schematic sectional view of an example oil recovery system that includes a reservoir that is in fluid communication with an injection well and a production well during enhanced oil recovery operations, in accordance with an embodiment of the present invention.

[021] Figure 2 is a schematic sectional view of an example oil recovery system that includes a reservoir that is in fluid communication with an injection well and a production well equipped with a pair of electrodes during enhanced oil recovery operations, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[022] The system and method described herein are directed to enhancing oil recovery of reservoirs, particularly by maximizing the distribution of an enhanced oil recovery fluid within a reservoir via electrokinetic-induced migration. A general treatise on conventional enhanced oil recovery is, "Basic Concepts in Enhanced Oil Recovery Processes," edited by M. Baviere (published for SCI by Elsevier Applied Science, London and New York, 1991).

[023] Referring to Figure 1, subterranean reservoir 10 includes a plurality of rock layers including hydrocarbon bearing strata or zone 11. Injection well 13 extends into hydrocarbon bearing zone 11 of subterranean reservoir 10 such that injection well 13 is in fluid communication with hydrocarbon bearing zone 11. Subterranean reservoir 10 can be any type of subsurface formation in which hydrocarbons are stored, such as limestone, dolomite, oil shale, sandstone, or a combination thereof. Production well 15 is also in fluid communication with hydrocarbon bearing zone 11 of subterranean reservoir 10 in order to receive hydrocarbons therefrom. Production well 15 is positioned a predetermined lateral distance away from injection well 13. For example, production well 15 can be positioned between 100 feet to 10,000 feet away from injection well 13. As will be readily appreciated

by those skilled in the art, there can be additional injection wells 13 and production wells 15, such that production wells 15 are spaced apart from injection wells 13 at predetermined locations to optimally receive the hydrocarbons being pushed due to injections from injection wells 13 through hydrocarbon bearing zone 11 of subterranean reservoir 10. Furthermore, while not shown in Figure 1, injection well 13 and production well 15 can deviate from the vertical position such that in some embodiments, injection well 13 and/or production well 15 can be a directional well, horizontal well, or a multilateral well.

[024] As will be described in further detail below, in operation, an enhanced oil recovery (EOR) fluid 17 is injected into hydrocarbon bearing zone 11 of subterranean reservoir 10 through injection well 13. The EOR fluid 17 comprises a polar fluid or a fluid having a net total charge. For example, EOR fluid 17 can be water as it has an uneven distribution of electron density and therefore, comprises a polar molecule. In one or more embodiments, EOR fluid 17 comprises a polar gas. In one or more embodiments, EOR fluid 17 comprises a chemical or mixture of chemicals having a net total charge. For example, EOR fluid 17 can comprise oxidizing agents (e.g., peroxides, hypohalites, ozone, persulphates, permanganates), reducing agents (e.g. nascent hydrogen, organic acids), surfactants/co-surfactants, solvents/co-solvents, polymers, or a combination thereof.

[025] In some embodiments, EOR fluid 17 alters the physical properties of the formation or rock matrix of hydrocarbon bearing zone 11 such as by increasing the effective porosity and permeability of the matrix so that the hydrocarbons are more accessible and recoverable. For example, oil shale often contains large amounts of tightly bonded carbonates and pyrites that can be dissolved using acid, such as thiobacillus. Depletion of these carbonate minerals from the shale matrix, such as through bioleaching, results in newly formed cavities that effectively increases the porosity (e.g., from less than 0.5% to about 4 or 5%) and

permeability of the oil shale, thereby enhancing recovery of the hydrocarbons. In some embodiments, EOR fluid 17 penetrates into pore spaces of the formation contacting the trapped oil globules such that the oil trapped in the pore spaces of the reservoir rock matrix is released. For example, EOR fluid 17 can be a surface active agent reducing the interfacial tension between the water and oil in the subterranean reservoir such that the oil trapped in the pore spaces of the reservoir rock matrix is released.

[026] Referring to Figure 1, an electric field is generated through at least a portion of the hydrocarbon bearing zone 11 to induce electrokinetic migration of EOR fluid 17. Electrokinetic induced migration allows for the EOR fluid 17 to contact portions of the reservoir that previously were unswept due to the limitations of traditional hydraulic injection, thereby enhancing recovery of hydrocarbons from hydrocarbon bearing zone 11 of subterranean reservoir 10 through production well 15. The electric field is generated by electrodes that impose a low voltage direct current through at least the portion of the hydrocarbon bearing zone 11 between injection well 13 and production well 15.

[027] In one embodiment, one or more electrodes are placed in communication with injection well 13 such that the electrically charged injection well acts as either an anode or a cathode. Similarly, one or more electrodes are placed in communication with production well 15 such that the electrically charged production well acts as an opposing cathode or anode to injection well 13. The respective charges create an electric current in the reservoir fluids contained within hydrocarbon bearing zone 11 of subterranean reservoir 10, which induces electrokinetic migration of EOR fluid 17 such that it is distributed within hydrocarbon bearing zone 11 of subterranean reservoir 10. One skilled in the art will appreciate that additional electrodes can be placed in locations other than in communication with injection well 13 and production well 15, such that an electric field is created that is

capable of directing EOR fluid 17 to a plurality of areas of within subterranean reservoir 10. In some embodiments, the electrodes are positioned directly within the hydrocarbon bearing zone 11. In some embodiments, the electrodes are positioned at locations above or below hydrocarbon bearing zone 11 such as within rock layers adjacent to hydrocarbon bearing zone 11.

[028] The electrodes can be made of any conductive material such as carbon or graphite. Electrodes of carbon and graphite are generally more resistant to corrosion. In another embodiment, the electrodes are conductive polymeric materials or intrinsically conducting polymers (ICPs), which also inhibit corrosion. In one embodiment, the electrodes create a low voltage direct current of less than about 10 volts per meter (V/m). In another embodiment, the electrodes create a low voltage direct current of less than about 20 volts per meter (V/m). In another embodiment, the electrodes create a low voltage direct current of less than about 50 volts per meter (V/m). In some embodiments, the low voltage direct current is periodically pulsed or reversed, which can help prevent buildup of acidic conditions at the cathode. In one embodiment, the frequency of pulsing and/or reversal of polarity is less than about a second. In another embodiment, the frequency of pulsing and/or reversal of polarity is greater than about a minute, such as ranging from periods of minutes to days.

[029] Figure 2 shows an embodiment of the present invention in which injection well 13 and production well 15 are equipped with a pair of electrodes 21, 23, respectively. A power source 25 is provided such that the positive and negative terminals are connected to electrodes 21, 23. The size of the power source is dependent on the size and characteristics of the reservoir. The size of the power source is however, large enough to sufficiently produce a low voltage direct current through at least a portion of the hydrocarbon bearing zone 11. In one embodiment, the positive terminal of power source 25 is in communication

with electrode 21 such that electrode 21, which is coupled to injection well 13, acts as an anode. The negative terminal of power source 25 is in communication with electrode 23 such that electrode 23, which is coupled to production well 15, acts as a cathode. In another embodiment, the positive and negative terminals of the power source 25 are switched such that the positive terminal of power source 25 is in communication with electrode 23 and the negative terminal of power source 25 is in communication with electrode 21. Here, injection well 13 acts as the cathode and production well 15 acts as the anode. In either embodiment, the pair of electrodes 21, 23 generates an electric field through at least a portion of the hydrocarbon bearing zone 11 to induce electrokinetic migration of EOR fluid 17. In other embodiments (not shown in Figure 2), electrodes 21, 23 are positioned in locations other than being coupled to injection well 13 and production well 15. The electrodes can also be positioned at locations above or below hydrocarbon bearing zone 11 such as within rock layers adjacent to hydrocarbon bearing zone 11. Additionally, a plurality of electrodes can be interspersed within subterranean reservoir 10 such that an electric field is created to drive EOR fluid 17 to unswept areas within hydrocarbon bearing zone 11.

[030] Therefore, embodiments of the present invention utilize electrokinetic-induced migration to overcome the fluid channeling limitations related to traditional hydraulic injection. In particular, a low voltage direct current is used to move or distribute EOR fluid 17 within the saturated porous media of the reservoir. For example, polar fluids or fluids having a net charge, including water, gas, surfactants, dissolved species, colloids, and micelles, can be moved rapidly through porous media under the influence of a direct current. In general, the rate of movement is associated with the power output of the power source, porosity of the reservoir matrix, and charge density. Further, the rate of migration of the EOR fluid 17 is independent of the hydraulic conductivity. Accordingly, as EOR fluid 17 migrates through the subterranean reservoir the rate of movement is independent of the

permeability and connectivity of the porous rock matrix. For example, EOR fluid 17 under electrokinetics migration can penetrate through rocks having a very small porosity, such as a porosity of 0.02% or less. EOR fluid 17 is therefore distributed to portions of the subterranean reservoir where trapped oil is located, such as those areas where traditional enhanced oil recovery floods have not swept. One skilled in the art will recognize that this is advantageous as injected EOR fluid 17, such as water during an induced water flood, can be mobilized from one portion of the reservoir where oil saturations are low into another portion of the reservoir where oil saturations are high.

[031] In one embodiment, EOR fluid 17 penetrates into pore spaces of the formation contacting the trapped oil globules such that the oil trapped in the pore spaces of the reservoir rock matrix is released by reducing the interfacial tension between the water and oil in the subterranean reservoir. For example, EOR fluid 17 can comprise at least one surfactant or a component that will produce at least one surfactant in situ having a net total charge. EOR fluid 17 can produce naturally occurring surfactants, such as from a biologically mediated reaction. Alternatively, EOR fluid 17 can produce surfactant in situ as a by-product of an induced process. For example, one or more compounds can be injected into the reservoir such that they react with reservoir materials to produce a surfactant. In another embodiment, one or more compounds can be injected into the reservoir that when mixed in the rock matrix react with each other to produce surfactant. Examples of surfactants that can be utilized for as or in EOR fluid 17 include anionic surfactants, cationic surfactants, amphoteric surfactants, non-ionic surfactants, and a combination thereof. As a skilled artisan may appreciate, the surfactant(s) selection may vary depending upon such factors as salinity and clay content in the reservoir. The surfactants can be injected in any manner such as in an aqueous solution, a surfactant-polymer (SP) flood or an alkaline-surfactant-polymer (ASP) flood. The surfactants can be injected continuously or in a batch process.

[032] EOR fluid 17 can comprise anionic surfactants such as sulfates, sulfonates, phosphates, or carboxylates. Such anionic surfactants are known and described in the art in, for example, SPE 129907 and U.S. Patent No. 7,770,641, which are both incorporated herein by reference. Example cationic surfactants include primary, secondary, or tertiary amines, or quaternary ammonium cations. Example amphoteric surfactants include cationic surfactants that are linked to a terminal sulfonate or carboxylate group. Example non-ionic surfactants include alcohol alkoxylates such as alkylaryl alkoxy alcohols or alkyl alkoxy alcohols. Currently available alkoxylated alcohols include Lutensol® TDA 10EO and Lutensol® OP40, which are manufactured by BASF SE headquartered in Rhineland-Palatinate, Germany. Neodol 25, which is manufactured by Shell Chemical Company, is also a currently available alkoxylated alcohol. Chevron Oronite Company LLC, a subsidiary of Chevron Corporation, also manufactures alkoxylated alcohols such as L24-12 and L14-12, which are twelve-mole ethoxylates of linear carbon chain alcohols. Other non-ionic surfactants can include alkyl alkoxylated esters and alkyl polyglycosides. In some embodiments, multiple non-ionic surfactants such as non-ionic alcohols or non-ionic esters are combined. The surfactant(s) of EOR fluid 17 can be any combination or individual anionic, cationic, amphoteric, or non-ionic surfactant so long as EOR fluid 17 has a net total charge.

[033] In one embodiment, electrokinetics is utilized for environmental treatment of wastes (ex situ and/or in situ). In particular, electrokinetics can enhance chemical treatment of contaminated soil or sediment. The contaminant may be organic, such as oil or solvent, or inorganic, such as mercury and arsenic. The EOR fluid can include a surfactant that reduces the interfacial tension between oil and water, thereby increasing the solubility of the contaminant.

[034] Applications of electrokinetic-induced migration are illustrated in U.S. Patent No. 7,547,160 and in "Electrokinetic Migration of Permanganate Through Low-Permeability Media," by D.A. Reynolds et al., Ground Water, Jul-Aug 2008, 46(4), pp. 629-37, which are both incorporated herein by reference. These publications illustrate rapid electrokinetic-induced migration of an oxidant (potassium permanganate) through low permeability clay material. In particular, the oxidant is delivered through the low permeability clay material at orders of magnitude faster than that of hydraulically induced flow.

[035] For example, the advantages of electrokinetic-induced migration over traditional hydraulic delivery is illustrated in the following experiment. A thin glass tank having a width of about 4 cm was constructed to simulate a two-dimensional flow field through a heterogeneous porous media. House-brick sized pieces of clay, which represent low permeability features, were emplaced within a zone of contiguous glass beads. The glass beads represent the high permeability zones of channeled flow. The tank was saturated with water and a flow field was established across the apparatus by fixing the hydraulic head (water elevation) at different heights on either side of the tank. Potassium permanganate was introduced into one side of the tank and allowed to flow through the apparatus. The potassium permanganate was substantially distributed within the glass beads after two hours. However, essentially no infiltration into the clay bricks occurred, indicating that the potassium permanganate bypassed the low permeability zones. This experiment was repeated, however, an anode and cathode were placed at either end of the tank after the potassium permanganate had flowed through the apparatus for two hours. A low voltage direct current of approximately 10 volts per meter (V/m) was applied between the anode and cathode for 20 minutes. The clay blocks were dissected and showed that the potassium permanganate fully penetrated the clay bricks.

[036] Application of electrokinetic induced migration to enhance the distribution of an EOR fluid is disclosed. Use of electrokinetic induced migration allows for the EOR fluid to contact portions of the reservoir that previously were unswept due to the limitations of traditional hydraulic injection. In some embodiments, the EOR fluid further penetrates into pore spaces of the formation contacting the trapped oil globules, thereby reducing the interfacial tension between the water and oil in the reservoir and releasing the oil from the pore spaces.

[037] While in the foregoing specification this invention has been described in relation to certain preferred embodiments thereof, and many details have been set forth for purpose of illustration, it will be apparent to those skilled in the art that the invention is susceptible to alteration and that certain other details described herein can vary considerably without departing from the basic principles of the invention. For example, in one embodiment, electrokinetic migration is used to prevent corrosion or scale build-up in injection or production wells by migrating polar gases, such as hydrogen sulfide (H_2S), to portions of the subterranean reservoir away from the wells. In this case, the polar gases are naturally present in the reservoir rather than being injected through the injection well like the EOR fluid.

What is claimed is:

1. A method for enhancing hydrocarbon recovery in subterranean reservoirs, the method comprising:

(a) providing an injection well and a production well that extend into a hydrocarbon bearing zone of a subterranean reservoir and are in fluid communication therewith;

(b) injecting an enhanced oil recovery fluid into the hydrocarbon bearing zone through the injection well;

(c) generating an electric field through at least a portion of the hydrocarbon bearing zone to induce electrokinetic migration of the enhanced oil recovery fluid; and

(d) recovering hydrocarbons from the hydrocarbon bearing zone of the subterranean reservoir through the production well.

2. The method of claim 1, wherein the electric field is generated by emitting a direct current less than about 50 volts per meter between a pair of electrodes.

3. The method of claim 1, wherein the electric field is generated by emitting a direct current between a pair of electrodes having opposite charges and being spaced apart from one another within the hydrocarbon bearing zone.

4. The method of claim 1, wherein the electric field is generated by emitting a direct current between a plurality of electrodes interspersed within the hydrocarbon bearing zone.

5. The method of claim 4, further comprising:

(e) adjusting the direct current emitted between one or more of the plurality of electrodes such that the enhanced oil recovery fluid migrates to unswept areas of the hydrocarbon bearing zone.

6. The method of claim 1, wherein the enhanced oil recovery fluid comprises a polar fluid.

7. The method of claim 1, wherein the enhanced oil recovery fluid has a net total charge.

8. The method of claim 1, wherein the enhanced oil recovery fluid comprises water.

9. The method of claim 1, wherein the enhanced oil recovery fluid comprises a surfactant.

10. The method of claim 1, wherein the enhanced oil recovery fluid comprises an oxidant.

11. The method of claim 1, wherein the enhanced oil recovery fluid alters a physical property of a formation matrix of the hydrocarbon bearing zone.

12. A method for enhancing hydrocarbon recovery in subterranean reservoirs, the method comprising:

(a) providing an injection well and a production well that extend into a hydrocarbon bearing zone of a subterranean reservoir and are in fluid communication therewith;

(b) providing a pair of electrodes having opposite charges and being spaced apart from one another within the hydrocarbon bearing zone;

(c) injecting an enhanced oil recovery fluid into the hydrocarbon bearing zone through the injection well;

(d) emitting a direct current between the pair of electrodes to induce electrokinetic migration of the enhanced oil recovery fluid; and

(e) recovering hydrocarbons from the hydrocarbon bearing zone of the subterranean reservoir through the production well.

13. The method of claim 12, wherein the direct current is less than about 50 volts per meter.

14. The method of claim 12, wherein the direct current is periodically pulsed.

15. The method of claim 12, wherein polarity of the pair of electrodes is periodically reversed.

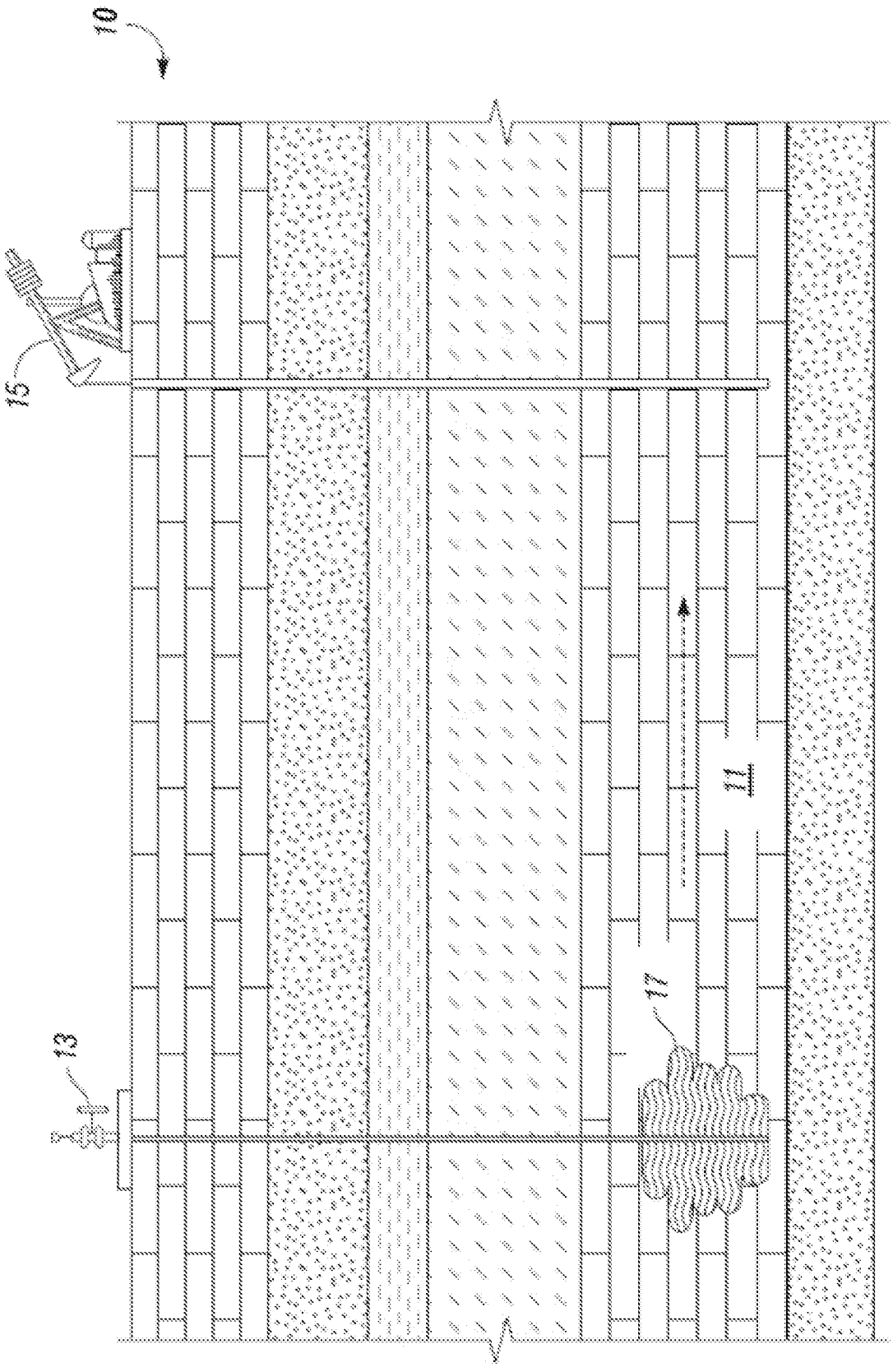

FIG. 1

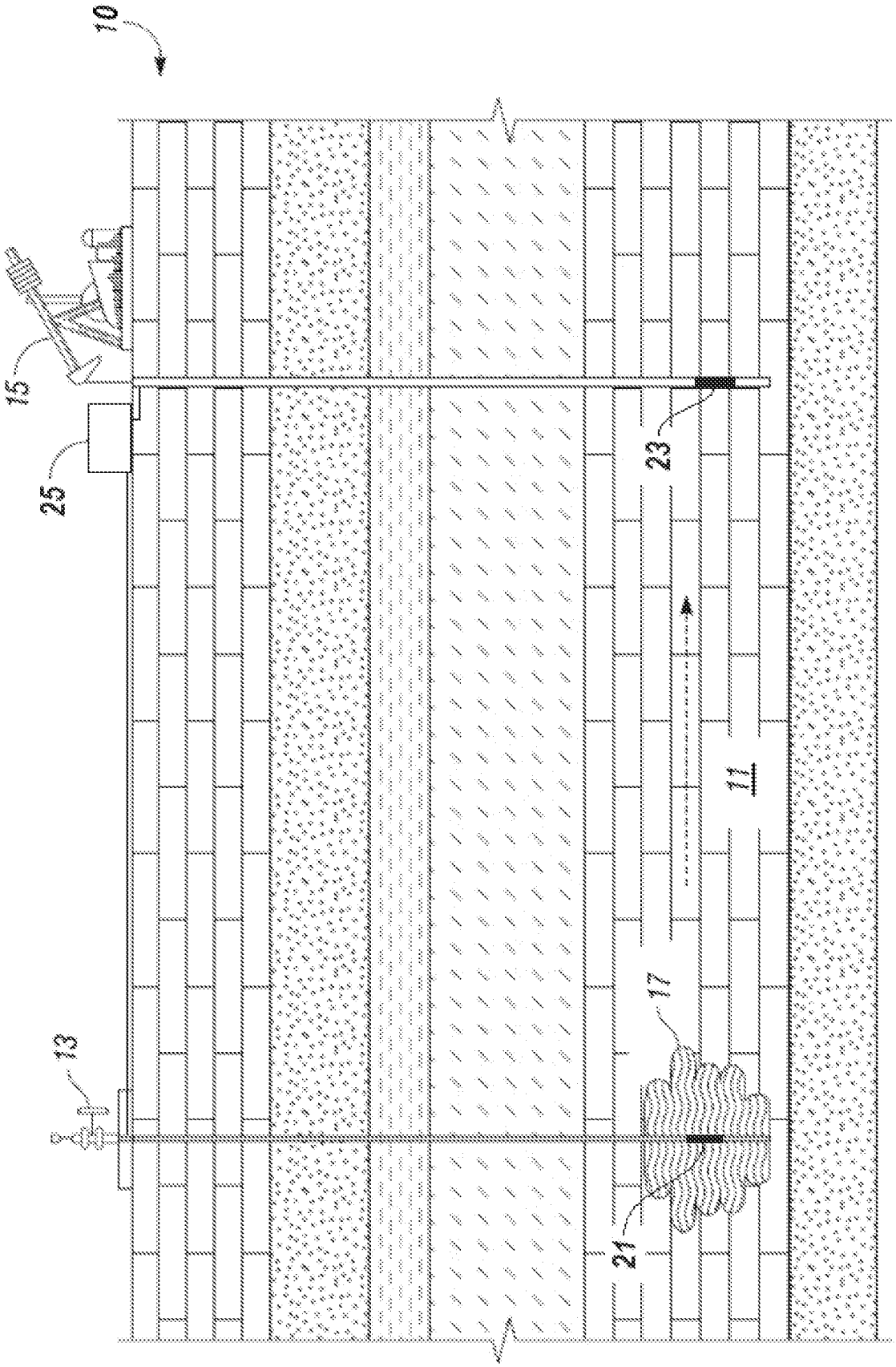

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/040782

A. CLASSIFICATION OF SUBJECT MATTER

E21B 43/24(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B 43/24; E21B 43/22; E21B 43/16

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: an injection well, a production well, an enhanced oil recovery fluid, EOR fluid, a polar fluid, electrokinetic-induced migration

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 04228854 A (SACUTA; ALEKSY) 21 October 1980 See columns 3,4, claim 1 and figure 1	1,3,6-12,14,15 2,4,5,13
Y	US 04651825 A (WILSON; ROBERT) 24 March 1987 See column 6 and figure 4	2,4,5,13
A	US 7770641 B2 (DWARAKANATH VARADARAJAN et al.) 10 August 2010 See abstract and figure 1	1-15
A	US 04084637 A (TODD; JOHN C.) 18 April 1978 See columns 4,5 and figure 1	1-15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 FEBRUARY 2012 (16.02.2012)	**17 FEBRUARY 2012 (17.02.2012)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2011/040782

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 04228854 A	21.10.1980	None	
US 04651825 A	24.03.1987	None	
US 7770641 B2	10.08.2010	AR069810A1	17.02.2010
		AU 2008-338633 A1	25.06.2009
		CA 2708803 A1	25.06.2009
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