US 20140124196A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2014/0124196 A1**

Sunde et al.

(43) **Pub. Date: May 8, 2014**

(54) **OPTIMIZING ENHANCED OIL RECOVERY BY THE USE OF OIL TRACERS**

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(21) Appl. No.: **13/827,639**

(22) Filed: **Mar. 14, 2013**

Related U.S. Application Data

(60) Provisional application No. 61/623,946, filed on Apr. 13, 2012.

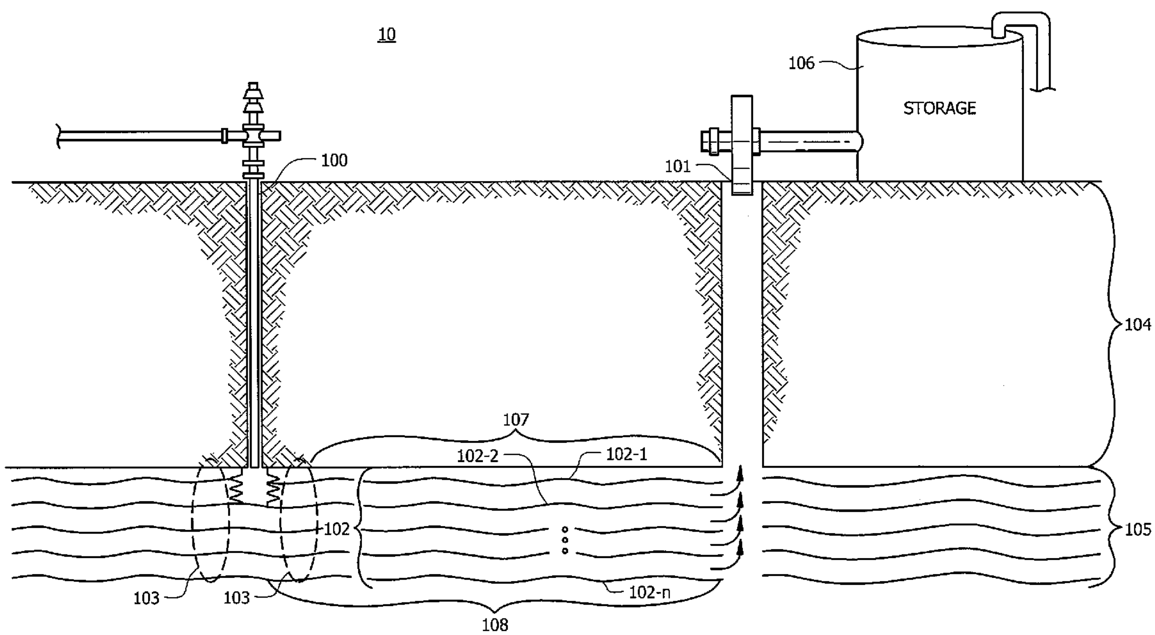
Publication Classification

(51) **Int. Cl.**
E21B 43/16 (2006.01)
E21B 47/00 (2006.01)

(52) **U.S. Cl.**
CPC *E21B 43/16* (2013.01); *E21B 47/00* (2013.01)
USPC **166/250.12**

(57) **ABSTRACT**

A method of optimizing recovery of oil from a formation that includes injecting an oil tracer into an injection well in the formation and applying a tertiary oil recovery process for recovering the oil from the formation. A production well is monitored to detect the oil tracer in oil from the production wells within particular times. The method also includes modifying the tertiary oil recovery process based on the detection of the oil tracer in oil from the production well.



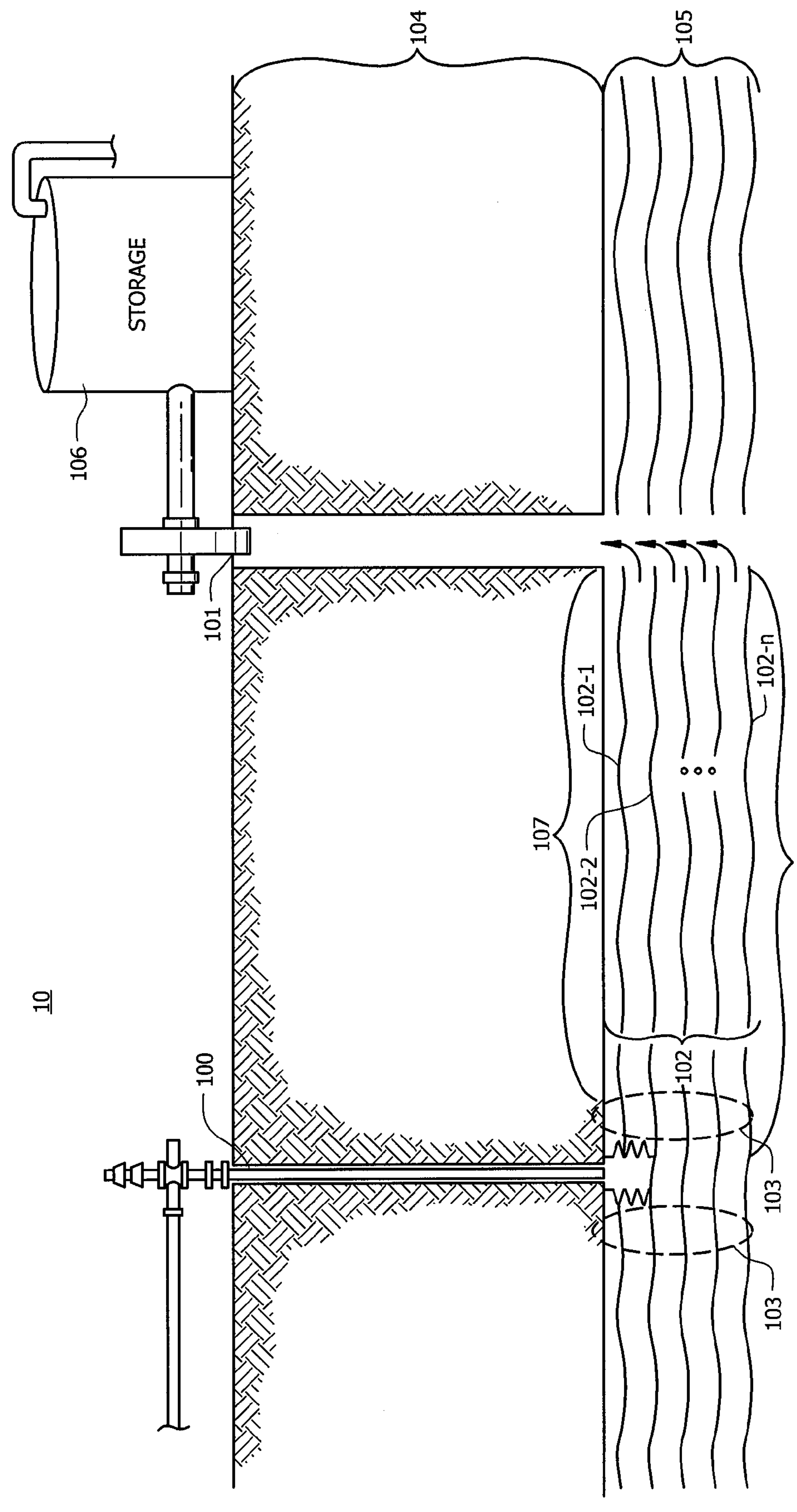

10
STORAGE
106
104
105
101
100
102-1
102-2
102-n
102
103
103
107
108

FIG. 1

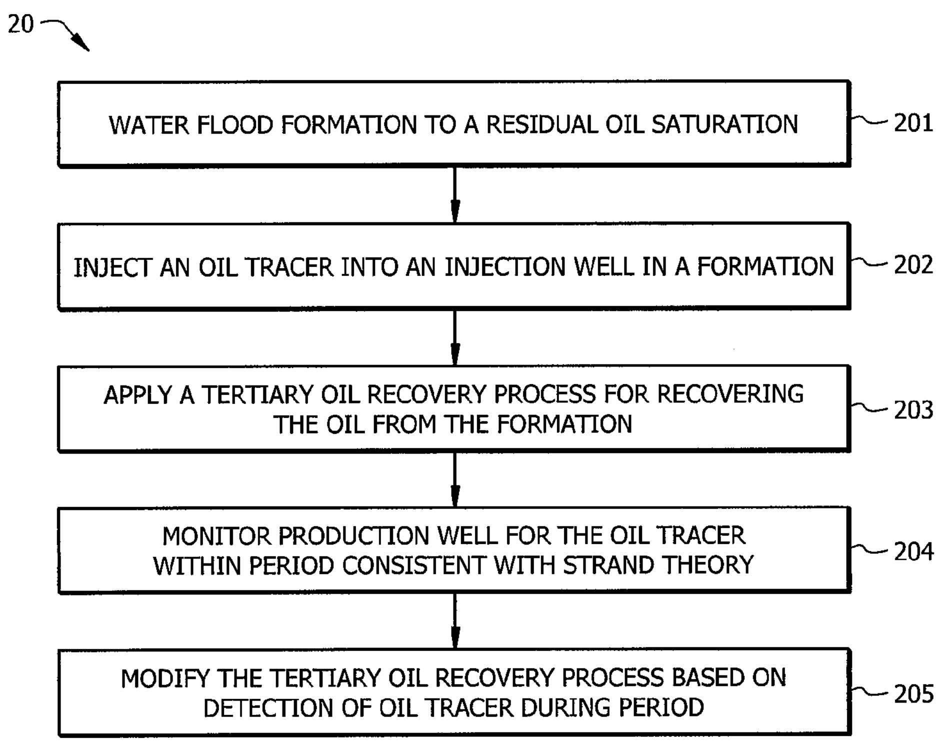

20
WATER FLOOD FORMATION TO A RESIDUAL OIL SATURATION
201
INJECT AN OIL TRACER INTO AN INJECTION WELL IN A FORMATION
202
APPLY A TERTIARY OIL RECOVERY PROCESS FOR RECOVERING THE OIL FROM THE FORMATION
203
MONITOR PRODUCTION WELL FOR THE OIL TRACER WITHIN PERIOD CONSISTENT WITH STRAND THEORY
204
MODIFY THE TERTIARY OIL RECOVERY PROCESS BASED ON DETECTION OF OIL TRACER DURING PERIOD
205

FIG. 2

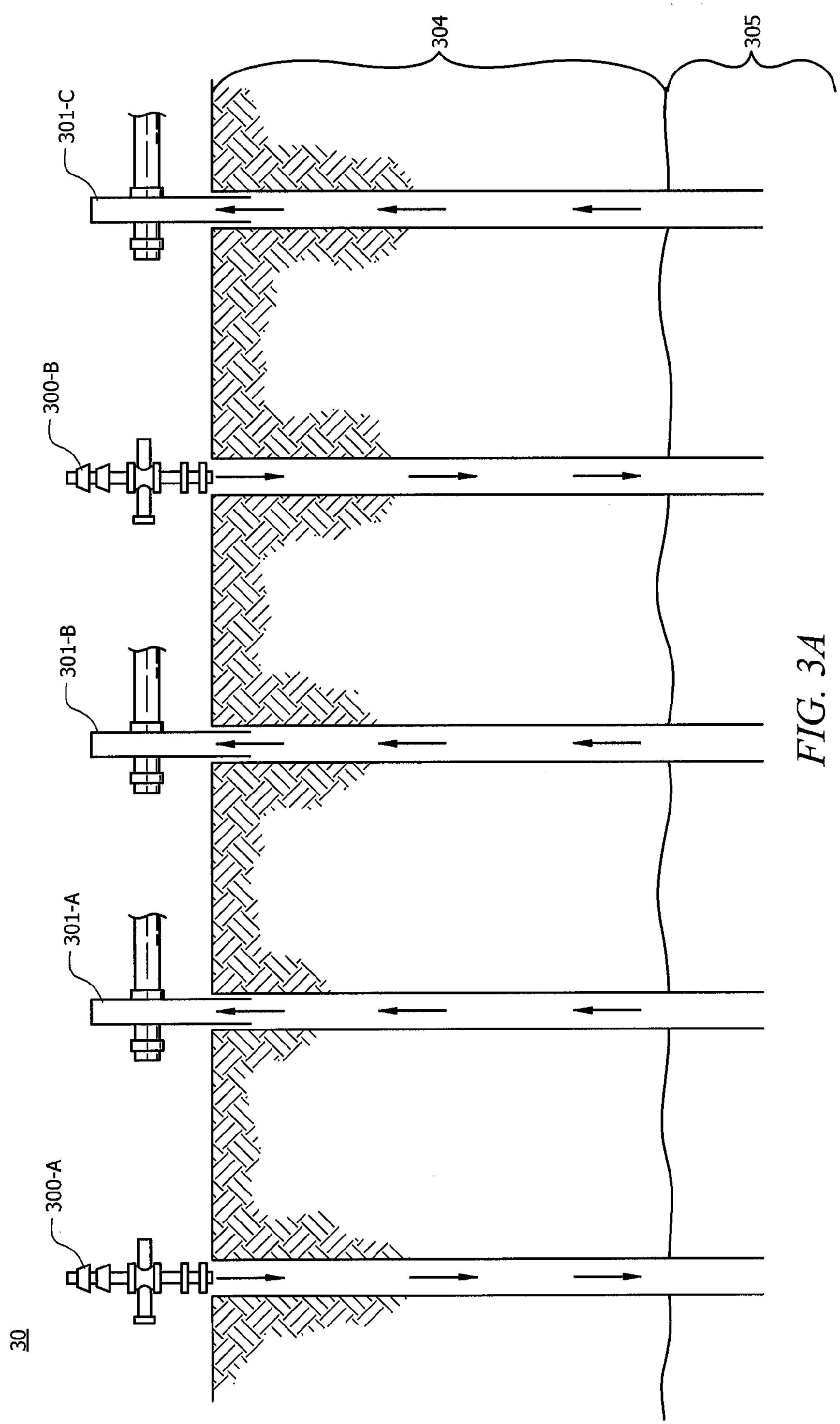


FIG. 3A

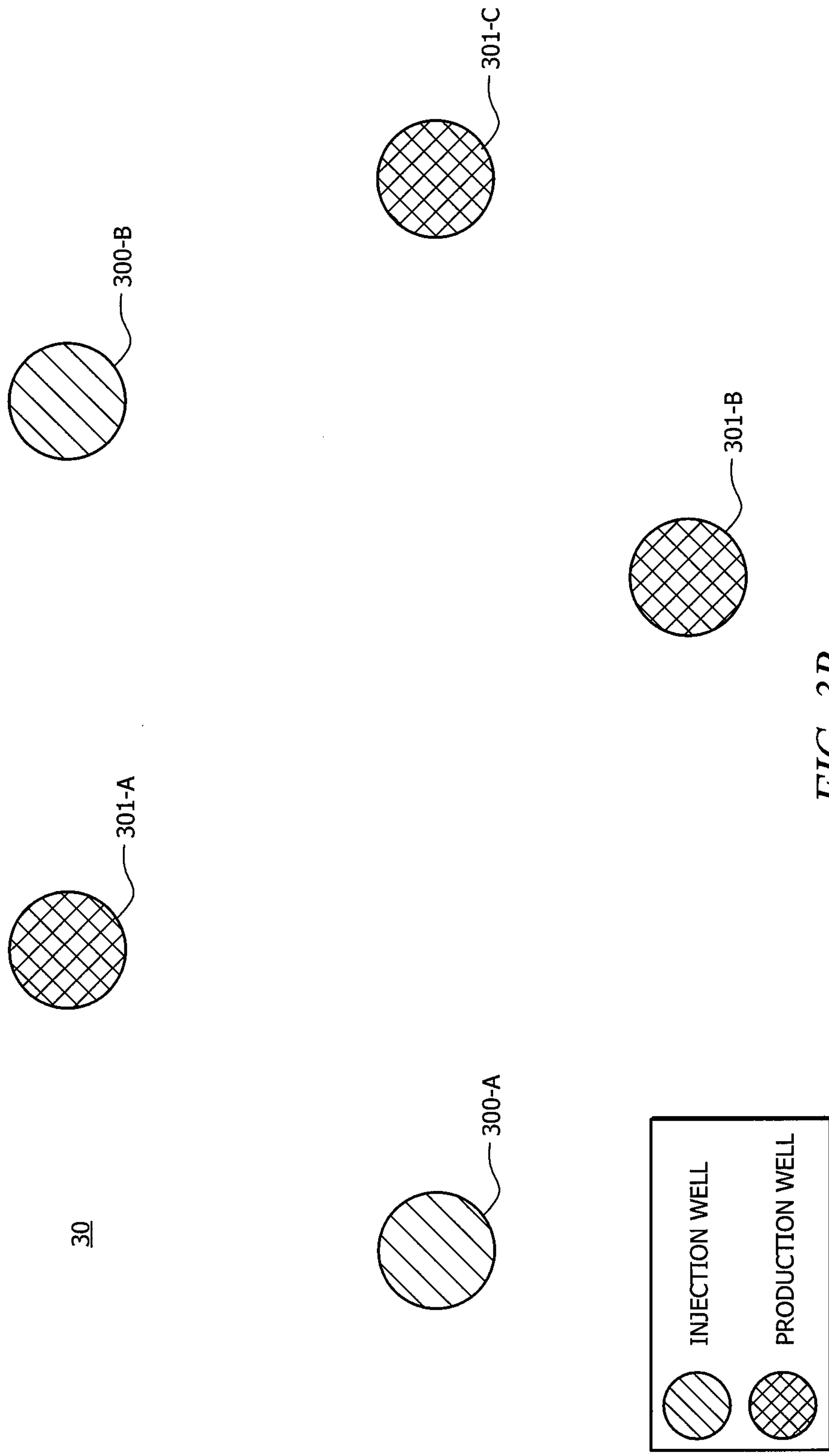


FIG. 3B

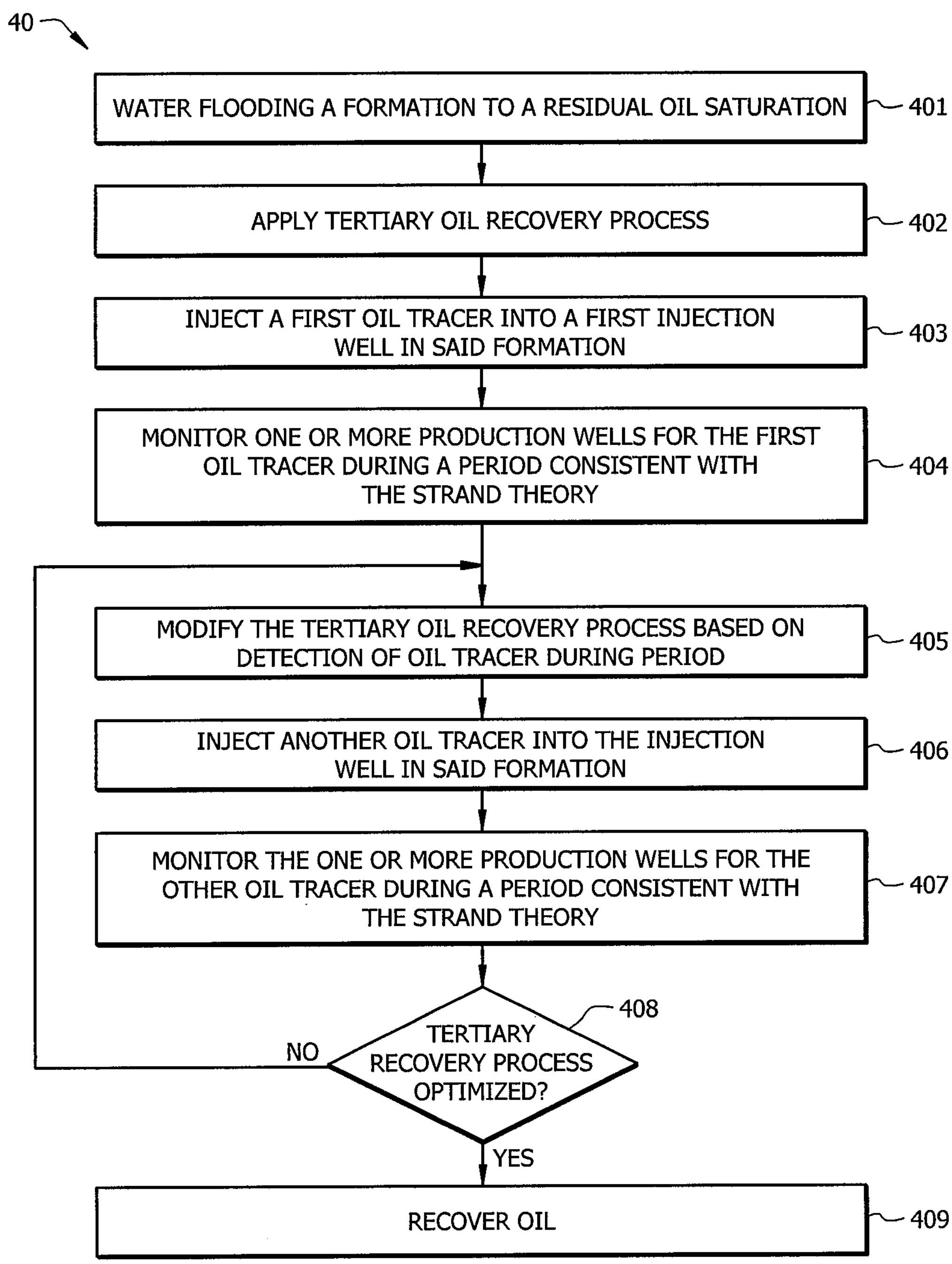
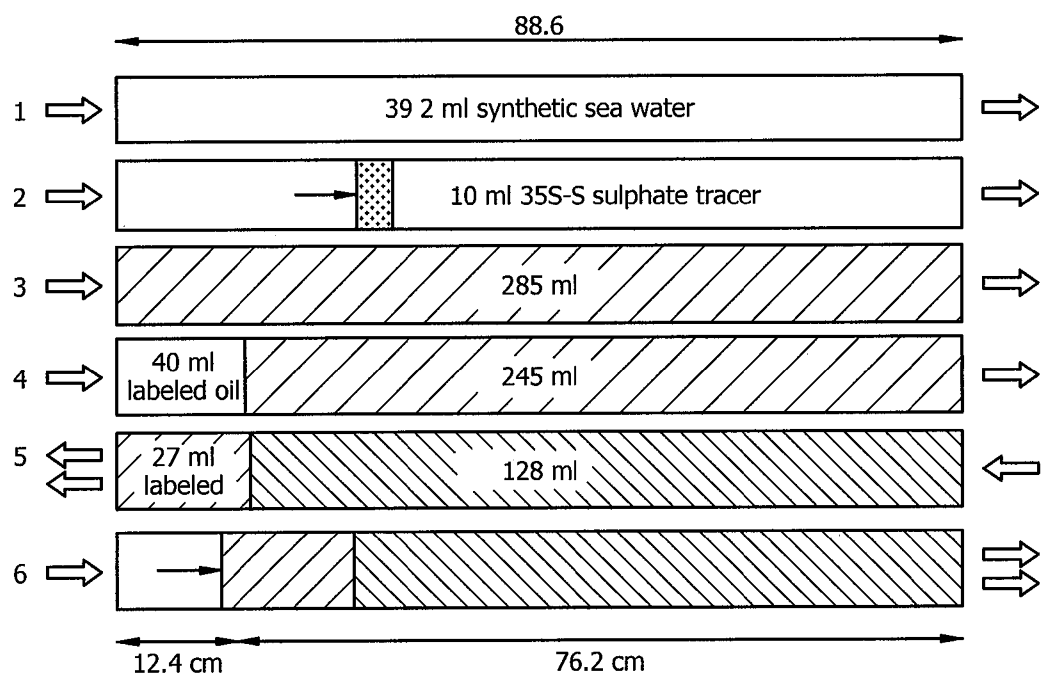

40
WATER FLOODING A FORMATION TO A RESIDUAL OIL SATURATION
401
APPLY TERTIARY OIL RECOVERY PROCESS
402
INJECT A FIRST OIL TRACER INTO A FIRST INJECTION WELL IN SAID FORMATION
403
MONITOR ONE OR MORE PRODUCTION WELLS FOR THE FIRST OIL TRACER DURING A PERIOD CONSISTENT WITH THE STRAND THEORY
404
MODIFY THE TERTIARY OIL RECOVERY PROCESS BASED ON DETECTION OF OIL TRACER DURING PERIOD
405
INJECT ANOTHER OIL TRACER INTO THE INJECTION WELL IN SAID FORMATION
406
MONITOR THE ONE OR MORE PRODUCTION WELLS FOR THE OTHER OIL TRACER DURING A PERIOD CONSISTENT WITH THE STRAND THEORY
407
TERTIARY RECOVERY PROCESS OPTIMIZED?
408
NO
YES
RECOVER OIL
409

FIG. 4



88.6
1
39 2 ml synthetic sea water
2
10 ml 35S-S sulphate tracer
3
285 ml
4
40 ml
labeled oil
245 ml
5
27 ml
labeled
128 ml
6
12.4 cm
76.2 cm

FIG. 5

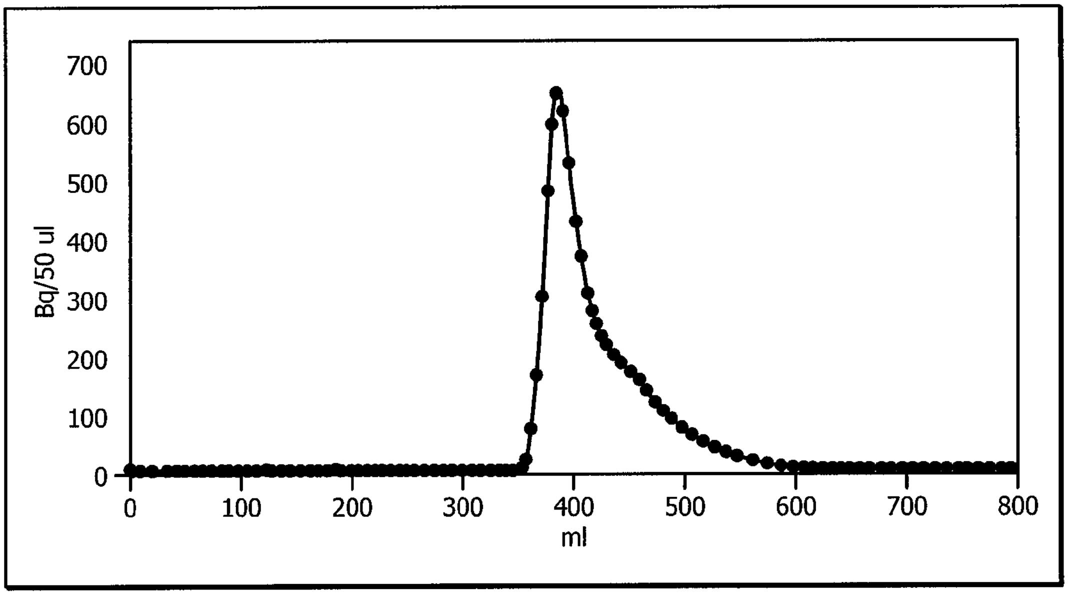

700
600
500
400
300
200
100
0
Bq/50 ul
0
100
200
300
400
500
600
700
800
ml

FIG. 6A

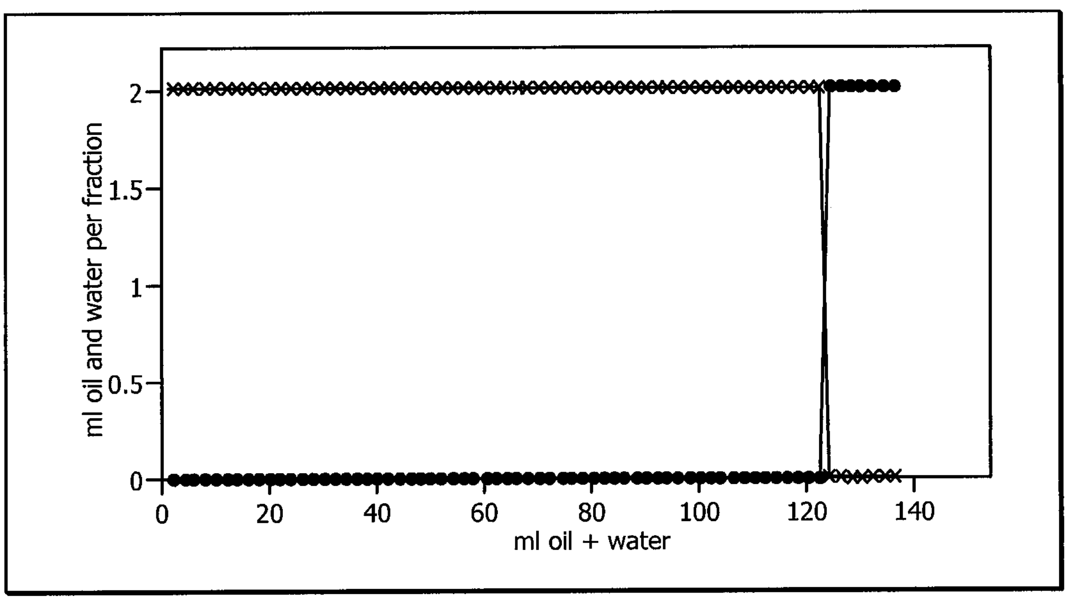

2
1.5
1
0.5
0
ml oil and water per fraction
0
20
40
60
80
100
120
140
ml oil + water

FIG. 6B

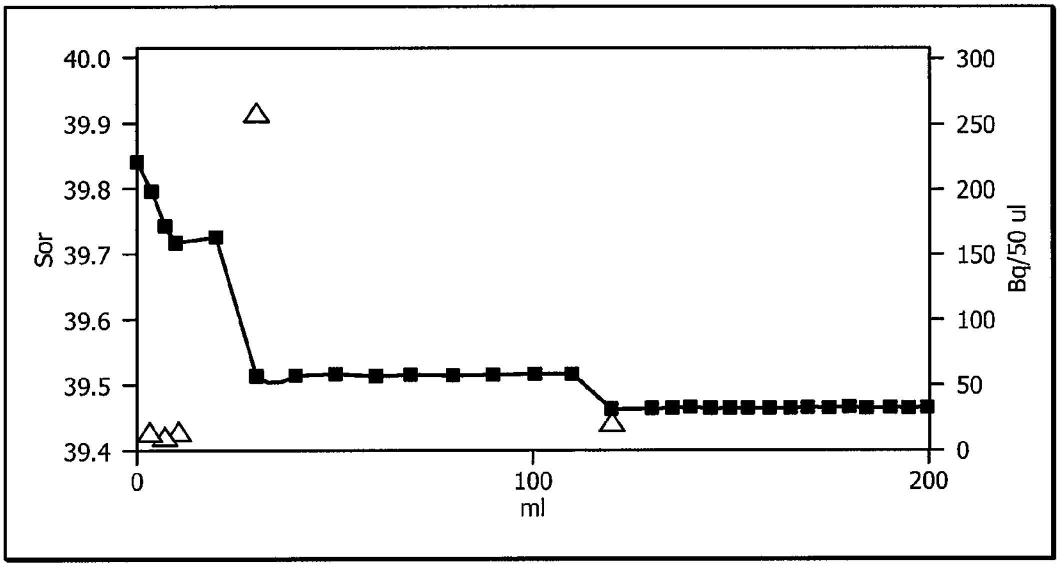

40.0
39.9
39.8
39.7
39.6
39.5
39.4
Sor
0
100
200
ml
300
250
200
150
100
50
0
Bq/50 ul

FIG. 6C

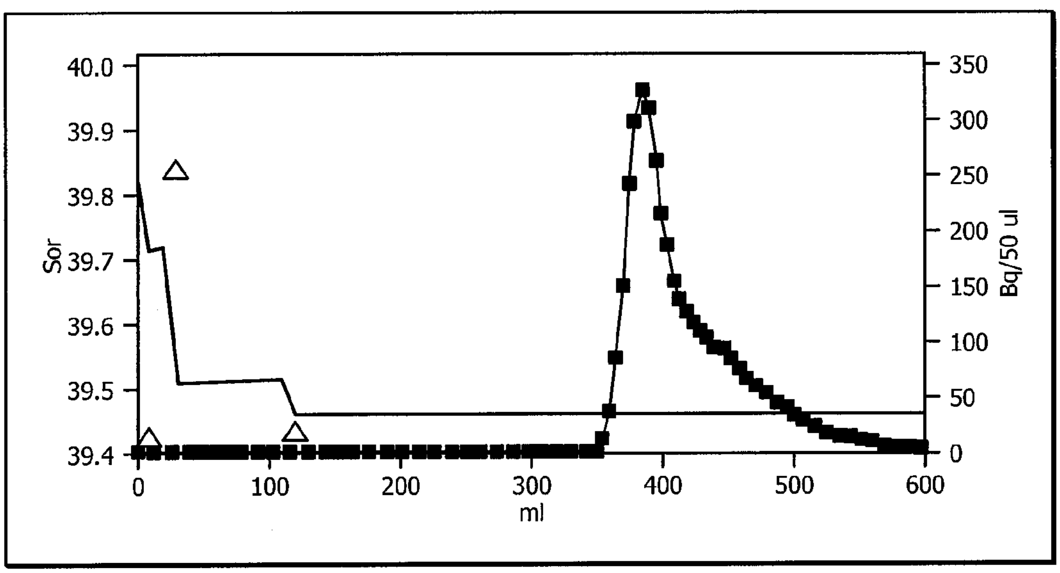

40.0
39.9
39.8
39.7
39.6
39.5
39.4
Sor
0
100
200
300
400
500
600
ml
350
300
250
200
150
100
50
0
Bq/50 ul

FIG. 6D

OPTIMIZING ENHANCED OIL RECOVERY BY THE USE OF OIL TRACERS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to co-pending U.S. Provisional Patent Application No. 61/623,946, entitled "IDENTIFICATION OF OPTIMAL INJECTOR/PRODUCER WELL CONFIGURATION FOR ENHANCED OIL RECOVERY BY THE USE OF OIL TRACERS," filed Apr. 13, 2012, the disclosure of which is hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Crude oil remains an important energy source. Crude oil producers typically produce oil by drilling wells into underground oil reservoirs in a formation. For some wells, the natural pressure of the oil is sufficient to bring the oil to the surface. This is known as primary recovery. Over time, as oil is recovered by primary recovery for these wells, the natural pressure drops and becomes insufficient to bring the oil to the surface. When this happens, a large amount of crude oil may still be left in the formation. Consequently, various secondary and tertiary recovery processes may be employed to recover more oil. Secondary and tertiary recovery processes may include: pumping, water injection, natural gas reinjection, air injection, carbon dioxide injection or injection of some other gas into the reservoir.

[0003] Current models used to apply these secondary and tertiary recovery processes employ relative permeability, wettability and capillary forces as the key variables. These models are based on the prevailing theory in the art that the oil exists in the reservoir primarily as droplets after water flooding. According to the traditional models, when a continuous oil phase in a water-wet rock is displaced by water, the continuity of oil is broken at a given residual oil saturation where the residual oil is located as droplets within the 3-dimensional pore network. See e.g. Amyx, J. W, Bass, D. M. and Whiting R. L. 1960. *Petroleum Reservoir Engineering, Physical Properties*. McGraw-Hill, New York. ISBN 07-001600-3.

[0004] In the petroleum industry, tracers are used to track fluid flow, for example, in a formation. Water soluble, oil soluble and partitioning tracers are known to be used in tracking fluid flow. An oil soluble tracer is soluble in oil but not in water. A partitioning tracer has affinity for both oil and water. In other words, partitioning tracers are soluble in both oil and water. In an oil/water system, the partitioning tracer is in equilibrium between the oil phase and the water phase. The equilibrium constant of the partitioning tracer determines how much of the partitioning tracer is in the water phase as compared to the oil phase. The phrase "oil tracer," as used herein, means oil soluble tracer or partitioning tracer. The prevailing theory as to how the residual oil exists in a reservoir has influenced how tracers have been used to monitor fluid flow. For example, for partitioning tracers, though it is soluble in oil and water, its movement is usually determined by measuring tracer concentration in the water. Further, prevailing theory suggests that tracers will take a long time (e.g. months or years) to reach a production well after being injected into an injection well. Thus, current methods start monitoring the production wells long after the injection of the tracer and only after breakthrough of water tracer. Further, the current methods seek to identify a pulse (sharp increase and decline in concentration) of tracer in the production well.

BRIEF SUMMARY OF THE INVENTION

[0005] One aspect of arriving at the present disclosure involved a new theory that the oil in the reservoir exists primarily as long continuous strands as opposed to the prevailing theory in the art that the oil exists in the reservoir primarily as droplets after water flooding. According to the new theory, long strands of oil extend from an injector well to a producer well. Further to this theory, embodiments of the invention include using an oil tracer to identify when oil is delivered to a production well consistent with the existence of strands between an injection well and a production well. When such a phenomenon is identified, oil recovery methods that are applied to the formation may be optimized so as to increase oil recovery. The oil tracer can be an oil soluble tracer or a partial oil soluble tracer (partitioning tracer).

[0006] Embodiments of the invention include a method of recovering oil from a formation that comprises a production well and an injection well. The formation, having been water flooded to a residual oil saturation in all the formation or at least in part of the formation between the injection well and the production well, wherein water breakthrough has occurred in the production well. The method includes injecting an oil tracer into the injection well in the formation and applying a tertiary oil recovery process for recovering the oil from the formation. The method also includes monitoring oil recovered from the production well to detect oil tracer. The monitoring being conducted at least within a period that starts at the time the oil tracer is injected and ends 30 days after the oil tracer is injected or the period starts when the tertiary oil recovery process is started and ends 30 days after the oil recovery process is started.

[0007] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a more complete understanding of the present invention, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

[0009] FIG. **1** shows a diagram of a system for implementing methods according to embodiments of the invention; and

[0010] FIG. **2** shows a flow chart illustrating steps according to embodiments of the invention.

[0011] FIGS. **3**A-**3**B shows a diagram of a system for implementing methods according to embodiments of the invention; and

[0012] FIG. **4** shows a flow chart illustrating steps according to embodiments of the invention.

[0013] FIG. **5** shows a protocol set up for preparation of core experiments; and

[0014] FIGS. **6**A-**6**D shows results of production of water and oil tracer from core flooding experiments.

DETAILED DESCRIPTION OF THE INVENTION

[0015] FIG. **1** shows a diagram of a system for implementing methods according to embodiments of the invention. System **10** includes an injection well **100** and a production well **101** in oil bearing formation **105**. Oil **102** resides in oil-bearing formation **105**. Oil-bearing formation **105** may be any type of geological formation and may be situated under overburden **104**. Although formation **105** is shown as being onshore in FIG. **1**, it should be appreciated that formation **105** may be located onshore or offshore. According to the new theory, previously mentioned, oil **102** primarily exists as continuous phase strands **102-1** to **102-***n* within formation **105**. The strands are of various lengths and may extend from injection well **100** to production well **101** as shown. In addition, the strands are 3-dimensional in nature and may cross link to other strands throughout formation **105**. See E. Sunde, B.-L. Lillebø, T. Torsvik, SPE 154138, Towards a New Theory for Improved Oil Recovery from Sandstone Reservoirs (attached hereto as Appendix A), the disclosure of which is incorporated herein by reference in its entirety.

[0016] According to the new theory, oil **102** is trapped within formation **105**, not as distinct droplets, but as strands (e.g. strands **102-1** to **102-***n*) in portions of formation **105**'s network of pores small enough to put up resistance to the surrounding drag and pressure drop of surrounding water flow and keeps the oil from flowing to the production well **101**. Oil **102** is continuous and present throughout the pore networks between injection well **100** and production well **101**. Between the pore networks, there may be other parts of formation **105** where water flow has almost completely cleared out the oil.

[0017] In a three-dimensional system, the oil will self organize according to the sum of pressures acting on it and the available pore network, thereby also redistributing some of its surrounding film of water. This and the fact that oil and water will seek the greatest possible separation to minimize friction, will leave the residual oil in continuous oil strands occupying pore spaces in all three dimensions. However, the general orientation of the oil strands will be parallel to the direction of flow due to the effect of shear forces.

[0018] With regard to FIG. **1**, if formation **105** is at a residual oil saturation, it is expected that injector well **100** is connected to producer well **101** by oil strands **102-1-102-***n*. However, it will not be known if there are several or just a few oil strands providing the connection. That is, it will not be known whether there are sufficient strands between injection well **100** and producer well **101** to produce oil in sufficient quantities, when a recovery method such as water flooding is applied. Moreover, in a formation where there are a plurality of injection wells and a plurality of production wells it may be unknown if and to what extent these wells are interconnected by strands in accordance with the strand theory.

[0019] Identifying whether injector well **100** is connected to producer well **101** by oil strands **102-1-102-***n* may involve the use of an oil tracer. Once the connectivity by oil strands **102-1-102-***n* is identified between injector well **100** and producer well **101**, the oil recovery process can be tailored towards increasing production from production well **101**.

[0020] FIG. **2** shows a flow chart illustrating steps according to embodiments of the invention. Method **20** may include, at step **201**, waterflooding formation **105** to a residual oil saturation. In some instances, this may be evident because water breakthrough has occurred at a production well. Formation **105** may have other producer wells in addition to producer well **101**. Step **202** involves injecting an oil tracer via injection well **100**. The oil tracer may include tritium labeled tetradecane (37 MBq, tetradecane [1,2-3H]4, pentacosane ($C_{25}H_{52}$); hexacosane ($C_{26}H_{54}$), heptacosane ($C_{27}H_{56}$), octacosane ($C_{28}H_{58}$), nonacosane ($C_{29}H_{60}$), triacontane ($C_{30}H_{62}$), hentriacontane (C_31H_{64}), dotriacontane ($C_{32}H_{66}$), tritriacontane ($C_{33}H_{68}$), tetratriacontane ($C_{34}H_{70}$) and the like and combinations thereof. Some of the above oil tracers are disclosed in U.S. Pat. No. 6,331,436 entitled "Tracers For Heavy Oil." At step **203**, a tertiary oil recovery process is applied to recover oil from formation **105**. It should be noted that step **202**—injection of the oil tracer—may be done at the same time, before or after step **203**—tertiary oil recovery process—is started. The tertiary oil recovery process may include microbial enhanced oil recovery, surfactant injection, polymer injection, water injection, natural gas reinjection, air injection, carbon dioxide injection, other gas injection, pressure pulses (water hammers) and combinations thereof.

[0021] Produced oil from production well **101** is monitored for the presence of the oil tracer at step **204**. Consistent with the strand theory, it is assumed that once tertiary recovery step **203** has started, oil in the vicinity of injection well **100** and consequently the injected oil tracer may rapidly be produced at production well **101**. Consequently, the monitoring is conducted at least within a period that starts at the time the oil tracer is injected and ends 30 days after the oil tracer is injected. Alternatively, the period starts when the tertiary oil recovery process is started and ends 30 days after the tertiary oil recovery process has started. Embodiments of the invention may use a period fewer than the 30 days described above. The actual length of time will depend on the type of tertiary oil recovery process. For example, for gaseous oil recovery processes, it may be desirable that the period of monitoring starts at the time the oil tracer is injected and ends 7 days after the oil tracer is injected. Alternatively, the period may start when the tertiary oil recovery process is started and ends 7 days after the oil recovery process has started. The equivalent period for a surfactant flooding tertiary oil recovery process is about 30 days. It should be noted that although a period is identified herein during which monitoring should be conducted to identify the existence of oil strands between an injection well and a production well, in embodiments of the invention, monitoring can continue beyond this period to gather other information and to further optimize the tertiary oil recovery process.

[0022] The monitoring includes determining whether the oil tracer is present in oil **102** produced from production well **101**. Various methods for making this determination may be used. For example, atomic absorption, atomic emission, plasma emission spectrometry, flame atomic absorption, X-ray fluorescence, mass spectrometry, and neutron activation. Some of the above methods are disclosed in U.S. Pat. No. 4,755,469 entitled "Oil Tracing Method." See also U.S. Pat. No. 6,016,191 entitled "Apparatus and Tool Using Tracers and Singles Point Optical Probes For Measuring Characteristics of Fluid Flow in a Hydrocarbon Well and Methods of Processing Resulting Signals." In embodiments of the invention, the monitoring process seeks to identify a consistent level of oil tracer in the oil produced as opposed to identifying a tracer pulse as is done for other tracer methods. See e.g. FIG. **6**A (showing a pulse of water tracer). As such, embodiments of the invention monitor the quantity of oil tracer in the oil produced from production well **101** as a function of time.

[0023] Based on whether the tracer is identified and at what concentrations, an analysis can be made as to whether and to what extent injection well **100** is connected to production well **101** by strands **102-1** to **102**-*n*. Form this, the tertiary oil recovery process may be modified to enhance the oil recovery process. Modifying the tertiary oil recovery process may involve changing any parameter in the tertiary oil recovery process that affects oil production. For example, changing the type and/or amount of surfactant injected during surfactant flooding, changing the type of gas used in gas injection, changing the amount and/or type of nutrients used in a microbial enhanced oil recovery process and the like.

[0024] FIGS. **3**A to **3**B show diagrams of a system for implementing methods according to embodiments of the invention. System **30** shows oil formation **305**, which has a plurality of injection wells and productions wells. Formation **305** has been water flooded to a residual oil saturation around the injection wells. In some instances, this may be evident because water breakthrough has occurred at a production well. Formation **305** is shown under overburden **304** and has drilled in it injection wells **300**-A and **300**-B and production wells **301**-A to **301**-C. In the configuration of system **30**, it is desirable to know how oil production from production wells would be affected by treatment of the injection wells. To answer this question, one or more oil tracers may be used as described below.

[0025] FIG. **4** shows a flow chart illustrating steps according to embodiments of the invention. Method **40** may include, at step **401**, water flooding formation **305** to a residual oil saturation. Step **402**, involves the application of a tertiary oil recovery process, examples of which are described above. At step **403**, a first oil tracer may be injected into, for example, injection well **300**-A. Step **404** involves monitoring one or more of production wells **301**-A-**301**-C to see if oil produced from these one or more production wells contain the first oil tracer. As described above, the monitoring may be conducted at least within a period that starts at the time the oil tracer is injected and ends 7 or 30 days after the oil tracer is injected. Alternatively the period starts one month after the tertiary oil recovery process is started and ends 7 or 30 days after the oil recovery process has started. The tertiary oil recovery process may then be modified at step **405** based on the detection of oil tracer in oil from production wells **301**-A-**301**-C during the monitoring period. Modification in embodiments may include changing any parameter in a tertiary oil recovery process that affects oil production. The changes may be based on the amount of oil tracer detected over time during the monitoring period. For example, changing the type or amount, or both of surfactant injected during surfactant flooding, changing the amount of gas used in gas injection, changing the amount or type, or both of nutrients used in a microbial enhanced oil recovery process and the like.

[0026] Subsequent to the modification at step **405**, a second tracer may be injected in injection well **300**-A, at step **406**. At step **407**, the one or more production wells **301**-A-**301**-C are monitored for the second oil tracer (and if desired the first oil tracer). Monitoring may be done for periods as described in step **404**. Based on the results of the monitoring steps **404** and **407**, a determination may be made whether the modification at step **405** achieved positive results in terms of oil recovery from formation **305**. Further, the production wells that provide the most improved results may be identified. At step **408**, a determination may be made whether the tertiary oil recovery process has been improved to the extent where it is considered optimized. If it is determined that the tertiary recovery process has not been optimized, then steps **405** to **408** may be repeated. If it is determined that the tertiary recovery process has been optimized, then the method may proceed to oil recovery at step **409**.

[0027] Embodiments of the invention may also include the injection of a second, third and fourth oil tracer in, for example, injection well **300**-B in a similar way as described above with injection well **300**-A. The tertiary oil recovery process is then applied via injection well **300**-B. This may be done at the same time, before or after the injection of first oil tracer as described above for injection well **300**-A. As such, each of production wells **301**-A to **300**-C may be monitored for the first, second, third and fourth oil tracers. In this way, the interrelationships between the various wells can be determined.

[0028] Based on the information learned from the method described above with respect to the interconnection of the wells, changes may be made to aspects of the tertiary recovery process being used for oil recovery. For example, changing the type or amount, or both of surfactant injected during surfactant flooding, changing amount of gas used in gas injection, changing the amount or type, or both of nutrients used in a microbial enhanced oil recovery process and the like.

[0029] Although methods according to embodiments of the present invention have been described with reference to the steps of FIG. **2** and FIG. **4**, it should be appreciated that operation of the present invention is not limited to the particular steps or the particular order of the steps illustrated in FIG. **2** and FIG. **4**. Accordingly, alternative embodiments may provide functionality as described herein using some or all the steps shown in FIG. **2** and FIG. **4** in a sequence different than that shown. For example, though the methods described above discusses the use of oil tracers for identifying the existence of oil strands between wells, embodiments of the invention may include methods other than those described above for identifying the existence of the oil strands. As such, embodiments of the invention include a method of optimizing recovery of oil from a formation that has a plurality of production wells and at least one injection well. The method includes a process for identifying the existence of oil strands between the at least one injection well and at least one of the plurality of production wells. The method also includes implementing a tertiary oil recovery process for recovering the oil from the formation based on the identification of oil strands and recovering oil from the formation as a result of the use of the implemented tertiary oil recovery process.

[0030] The use of the strand theory to optimize oil recovery as described herein gives unexpected results when compared with existing methods. For example, embodiments of the invention could result in an increase in production in the highest production well (the well having the largest pressure difference with the injection well) of a formation even if there are other production wells in between the highest production well and the injection well.

Laboratory Data and Up Scaling

[0031] The Strand theory has been verified in core flooding experiments with North Sea crude oil using oil and water soluble tracers. In this work, labelled oil was placed at the entrance of a core with residual oil, and flooded with brine. Oil was mobilized by a pressure pulse.

[0032] In the experiment described below water wet Bentheimer sandstone core was used. The physical properties of the core are shown in Table 1. The process of core preparation and flooding is visualized in FIG. **5**. Synthetic sea water containing 20.0 g NaCl, 4.0 g Na_2SO_4, 3.0 g $MgCl_2x6H_2O$, 0.5 g KCl and 0.15 g CaCl was used as the connate brine. A water soluble tracer; 35S labeled sodium sulphate (37 MBq, 1.0 mCi Sodium [35S] sulphate dissolved in 10 ml brine), and an oil tracer; tritium labeled tetradecane (37 MBq, tetradecane [1,2-3H]4, 1 mCi dissolved in 40 ml crude oil) was used. For tracer analysis 50 µl oil sample was mixed with 1.8 ml heptane and 18 ml Ultima Gold LLT. Water samples were prepared by mixing 100 µl water with 3 ml Ultima Gold LLT. All samples were analyzed in a Packard Bell scintillation counter.

[0033] As shown in FIG. **5**, the cylindrical sandstone core was prepared to resemble a reservoir in the residual situation having water and oil in representative positions and locating the oil tracer near the inlet. After filling the core with synthetic sea water, a volume of 35S-sulphate labelled brine was flooded through the core. The first water tracer emerged after flooding 345 ml of water (equivalent to 0.88 pore volumes), the peak was obtained after flooding of 385 ml (equivalent to 0.99 pore volumes) and 99.5% of the tracer was recovered after flooding 1.5 pore volumes (FIG. **6**A). The core was filled with North Sea crude oil and 40 ml tritium labelled oil was injected. The flow direction was reversed during water flooding to reach residual oil concentration, leaving the labelled oil at the inlet side at the start of the experiment (FIG. **6**B). The oil and water production profiles indicate water wet sandstone core, as expected from Bentheimer cores with low clay mineral content.

[0034] In order to initiate production of the residual oil the core was pressurized by pumping brine into the core with closed outlet valve to obtain 2 bars overpressure. A pressure pulse was generated by opening the valve and thereby depressurizing the core. This resulted in immediate production (within 10 seconds) of 1.0 ml oil. The oil was collected and the process of pressurizing and depressurizing was repeated twice, this time resulting in production of 0.2 and 0.1 ml oil. Following this, the injection pump rate was set to 0.1 ml/min and produced oil and water was collected in 6 ml fractions, one fraction per hour. Tritiated tetradecane was detected in all oil samples. The first oil fraction contained 233 Bq (total) of tritiated tetradecane tracer; the next two contained 40 and 30 Bq respectively. The 4th oil fraction contained 4133 Bq and was produced after flooding with 31 ml water (FIG. **6**C). In FIG. **6**D oil production and the production of oil and water tracers are plotted together.

TABLE 1

Properties of sandstone core and crude oil	
L (cm)	88.6
D (cm)	5.0
PV (cm^3)	392
Swi	0.27
Soi	0.73
Sor (%) at start pressure pulse	39.5
Kabs (mD)	1463
Kw	78.13
Flowrate, ml/minute	0.10
Crude oil density, g/cm^3 at 15° C.	0.834
Crude oil viscosity, cSt at 15° C.	2.85

PV; core pore volume, Swi; initial water saturation, Soi; initial oil saturation, Sor; % residual oil, Kabs; absolute permeability, Kw; effective water permeability at pressure pulse.

[0035] Results from the experiment described above show that the first oil produced contained oil tracer, in agreement with the continuous oil Strand theory, while the water tracer pulse moved as a piston through the core. In this experiment, the oil was produced within 10 seconds after opening the pressure valve. This means that tracer labelled oil must have moved at least 76.3 cm in 10 seconds, an oil tracer displacement of 460 cm/minute. In comparison the water tracer moved 88.6 cm in 3500 minutes, at a rate of 0.03 cm/minute. This shows that oil can move rapidly, over a long distance, independent of the water flooding rate. Hence, it has been observed the oil tracer to be transported from the entrance to the outlet of the core at a rate 10000 times faster than the water.

[0036] This laboratory experiment was designed to answer the question: How is residual oil transported in the reservoir? This question was also asked by Jones (Jones, S. C. 1985. Some Surprises in the Transport of Miscible Fluids in the Presence of a Second Immiscible Phase. *SPE J.* Paper SPE-12125 pp. 101-112.). Jones matched his observations with the current idea that residual oil resides in discontinuous oil droplets that are transported with water. He therefore expected that the first oil to be produced would be the oil closest to the outlet and the last oil produced would be the first oil mobilized at the injection end of the core. However, Jones unexpectedly found that the first oil mobilized by a surfactant slug was produced simultaneously with the oil closest to the outlet. In the alternative oil Strand theory described here, the oil strands can be produced sequentially, squeezed out by water flowing perpendicular to the oil strand. This would allow the oil located near the water injector to be produced together with the oil closest to the producer, in agreement with Jones findings.

[0037] The pressure pulse has been mathematically modeled and verified over one pore throat (Skaelaaen, I. 2010. Mathematical Modelling of Microbial Induced Processes in Oil Reservoirs. *PhD thesis*, University of Bergen, Bergen, Norway (2010)). The laboratory results are a scaling up from a pore length of approx. 20 microns to 0.76 meters, equivalent to approx. 4*104. A further scaling up to reservoir scale is only two more orders of magnitude.

[0038] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A method of optimizing recovery of oil from a formation comprising a production well and an injection well; said method comprising:

water flooding said formation to a residual oil saturation between said injection well and said production well;

after said residual oil saturation, injecting an oil tracer into said injection well in said formation;

applying a tertiary oil recovery process for recovering said oil from said formation;

monitoring said production well to detect said oil tracer, said monitoring being conducted within a period that starts at the time the oil tracer is injected and ends 30 days after the oil tracer is injected or the period starts when the tertiary oil recovery process is started and ends 30 days after the oil recovery process is started; and

modifying said tertiary oil recovery process based on a detection of said oil tracer in oil recovered from said production well during said period.

2. The method of claim **1** wherein said applying of said tertiary oil recovery process is started before said injection of said oil tracer.

3. The method of claim **1** wherein said tertiary oil recovery process includes a selection from the list consisting of: microbial enhanced oil recovery, surfactant injection, polymer injection, water injection, natural gas reinjection, air injection, air injection, carbon dioxide injection, other gas injection, pressure pulses and combinations thereof.

4. The method of claim **1** wherein said monitoring comprises determining the quantity of tracer detected as a function of time.

5. The method of claim **1** wherein said modification comprises a selection from the list consisting of: changing a type or amount of surfactant used in a surfactant flooding process, changing amount of gas used in a gas injection process, changing a type or amount of nutrients used in a microbial enhanced oil recovery process.

6. The method of claim **1** wherein said period is further limited to start at the time the oil tracer is injected and end 7 days after the oil tracer is injected or to start when the tertiary oil recovery process is started and end 7 days after the oil recovery process is started.

7. The method of claim **1** wherein said residual oil saturation is determined by detecting water breakthrough in said production well.

8. The method of claim **1** wherein the oil tracer is an oil soluble tracer.

9. The method of claim **1** wherein the oil tracer is a partitioning tracer.

10. A method of optimizing recovery of oil from a formation comprising a production well and an injection well; said method comprising:

water flooding said formation until water breakthrough occurs at said production well;

after said water breakthrough, injecting an oil tracer into said injection well in said formation;

applying a tertiary oil recovery process for recovering said oil from said formation;

monitoring said production well to detect said oil tracer, said monitoring being conducted within a period that starts at the time the oil tracer is injected and ends 30 days after the oil tracer is injected or the period starts when the tertiary oil recovery process is started and ends 30 days after the oil recovery process is started; and

modifying said tertiary oil recovery process based on a detection of said oil tracer in oil recovered from said production well during said period.

11. The method of claim **10** wherein said applying of said tertiary oil recovery process is started before said injection of said oil tracer.

12. The method of claim **10** wherein said tertiary oil recovery process includes a selection from the list consisting of: microbial enhanced oil recovery, surfactant injection, polymer injection, water injection, natural gas reinjection, air injection, air injection, carbon dioxide injection, other gas injection, pressure pulses and combinations thereof.

13. The method of claim **10** wherein said monitoring comprises determining the quantity of tracer detected as a function of time.

14. The method of claim **10** wherein said modification comprises a selection from the list consisting of: changing a type or amount of surfactant used in a surfactant flooding process, changing amount of gas used in a gas injection process, changing a type or amount of nutrients used in a microbial enhanced oil recovery process.

15. The method of claim **10** wherein said period is further limited to start at the time the oil tracer is injected and end 7 days after the oil tracer is injected or to start when the tertiary oil recovery process is started and end 7 days after the oil recovery process is started.

16. The method of claim **10** wherein the oil tracer is an oil soluble tracer.

17. The method of claim **10** wherein the oil tracer is a partitioning tracer.

18. A method of optimizing recovery of oil from a formation comprising a production well and an injection well; said method comprising:

water flooding said formation to a residual oil saturation between said injection well and said production well;

after said residual oil saturation, injecting an oil tracer into said injection well in said formation;

applying a tertiary oil recovery process for recovering said oil from said formation;

monitoring said production well to detect said oil tracer, said monitoring being conducted within a period that starts at the time the oil tracer is injected and ends 30 days after the oil tracer is injected; and

modifying said tertiary oil recovery process based on a detection of said oil tracer in oil recovered from said production well during said period.

19. The method of claim **18** wherein said applying of said tertiary oil recovery process is started before said injection of said oil tracer.

20. The method of claim **18** wherein said tertiary oil recovery process includes a selection from the list consisting of: microbial enhanced oil recovery, surfactant injection, polymer injection, water injection, natural gas reinjection, air injection, air injection, carbon dioxide injection, other gas injection, pressure pulses and combinations thereof.

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