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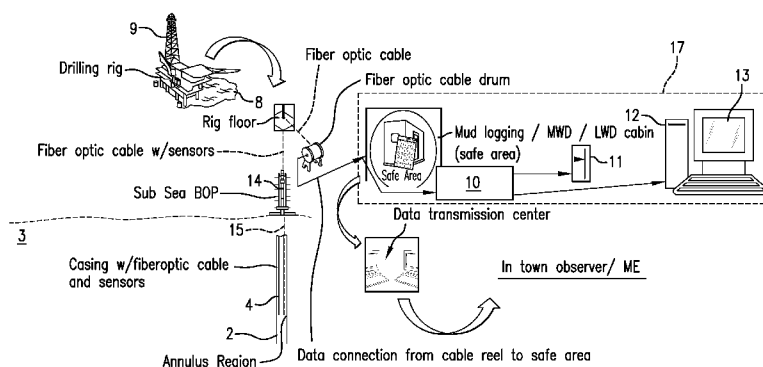


FIG. 1

(57) **Abstract:** Disclosed is an apparatus for completion of a well. The apparatus includes a tubular configured to be disposed in a wellbore penetrating the earth where an annulus region is defined between an exterior surface of the tubular and a wall of the wellbore. The apparatus further includes a plurality of sensors disposed in the annulus region and configured to sense hydrocarbons during cementing of the tubular to the wall of the wellbore. A receiver is disposed remote from the wellbore and configured to receive measurement data from the plurality of sensors and to provide an indication if hydrocarbons are sensed in the annulus region.

HYDROCARBON DETECTION IN ANNULUS OF WELL

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of an earlier filing date from U.S. Provisional Application Serial No. 61/496,252 filed June 13, 2011, the entire disclosure of which is incorporated herein by reference.

BACKGROUND

[0001] Completion of wells drilled into the earth typically requires a tubular such as a casing be inserted into a wellbore. The tubular is then cemented in place by circulating cement from inside the tubular to the annulus formed between the outside of the tubular and the wall of the wellbore. Once the cement is hardened, hydrocarbons can be extracted through the casing from a reservoir penetrated by the wellbore.

[0002] Circulating the cement can present certain challenges. If hydrocarbons start entering and channeling up in the annulus through the cement before the cement hardens, those hydrocarbons can flow improperly to a drilling rig at the surface of the earth or ocean resulting in a loss of hydrocarbons and an inefficient use of completion resources. Hence, it would be well received in the geophysical drilling industry if well completion techniques could be improved.

BRIEF SUMMARY

[0003] Disclosed is an apparatus for completion of a well. The apparatus includes a tubular configured to be disposed in a wellbore penetrating the earth where an annulus region is defined between an exterior surface of the tubular and a wall of the wellbore. The apparatus further includes a plurality of sensors disposed in the annulus region and configured to sense hydrocarbons during cementing of the tubular to the wall of the wellbore. A receiver is disposed remote from the wellbore and configured to receive measurement data from the plurality of sensors and to provide an indication if hydrocarbons are sensed in the annulus region.

[0004] Also disclosed is a method for completion of a well. The method includes: disposing a tubular in a wellbore penetrating the earth, an annulus region being defined between an exterior surface of the tubular and a wall of the wellbore; disposing a plurality of sensors in the annulus region, the plurality of sensors being configured to sense

hydrocarbons; receiving sensing data from the plurality of sensors using a receiver disposed remote from the wellbore; and using the sensing data to provide an indication with an indicator or display coupled to the receiver to indicate if hydrocarbons are sensed in the annulus region.

[0005] Further disclosed is a non-transitory computer-readable medium having computer-executable instructions for completion of a well by implementing a method. The method includes: receiving outputs from a plurality of sensors configured to sense hydrocarbons and disposed in an annulus region defined by an exterior surface of a tubular disposed in a wellbore penetrating the earth and a wall of the wellbore; detecting a presense of hydrocarbons in the annulus region using the outputs; and providing an indication if the presence of hydrocarbons is sensed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0007] FIG. 1 illustrates an exemplary embodiment of a drilling rig disposed at a surface of water for drilling a wellbore through the earth beneath the drilling rig;

[0008] FIG. 2 depicts aspects of a plurality of sensors distributed in an annulus between a tubular disposed in the wellbore and a wall of the wellbore;

[0009] FIG. 3 depicts aspects of a battery configured to power one or more sensors in the plurality of sensors or to function as a sensor; and

[0010] FIG. 4 presents one example of a method for completing a well.

DETAILED DESCRIPTION

[0011] A detailed description of one or more embodiments of the disclosed apparatus and method presented herein by way of exemplification and not limitation with reference to the Figures.

[0012] Disclosed are apparatus and method for completing a well that provide for a decrease in the probability of a loss of hydrocarbons.

[0013] FIG. 1 illustrates an exemplary embodiment of a drilling rig 9 disposed at a surface of water 8. The drilling rig is configured to drill a wellbore 2 through the earth 3 beneath the drilling rig 9 and the water 8. In terrestrial embodiments, the drilling rig 9 can be disposed at the surface of the earth 3. A tubular 4 such as a casing is disposed in the wellbore

2. An annulus region referred to as an annulus is defined by an exterior surface of the tubular 4 and a wall of the wellbore 2. The tubular 4 is configured to flow hydrocarbons extracted from a reservoir once the tubular 4 is secured in place. Securing the tubular 4 is accomplished with a cementing process in which cement is circulated into the annulus and then hardened in place.

[0014] Referring to FIG. 2, during cementing operations, a casing shoe 6 disposed at the distal end of the tubular 4 directs cement circulating in the tubular 4 into the annulus. A float collar 7 disposed in the tubular 4 above the casing shoe 6 prevents cement from flowing back up the tubular 4.

[0015] A plurality of sensors 5 is disposed in the annulus as shown in FIG. 2. The sensors 5 are configured to detect a presence and/or quantity of hydrocarbons, such as gas or oil, in the annulus. Non-limiting embodiments of the sensors 5 include temperature sensors, pressure sensors, hydrocarbon sensors configured to chemically detect gas or oil, and mud/fluid weight density sensors. The presence and/or quantity of hydrocarbons can be detected by these sensors by comparing measured data to hydrocarbon reference data. Generally, the plurality of sensors 5 is secured to the tubular 4 on the deck of the drilling rig 9 before the tubular 4 is placed in the wellbore 2. Straps or bands 16 can be used to secure the plurality of sensors 5 to the tubular 4. The plurality of sensors 5 can be disposed in groups at certain depths or they can be distributed along certain ranges of depth. In one embodiment, the plurality of sensors 5 is distributed between the casing shoe 6 and the float collar 7. In this area, it is likely that hydrocarbons will enter the annulus during cementing operations and thus may cause a blowout. The plurality of sensors 5 may also include additional sensors 5 disposed higher up in the annulus. It can be appreciated that the additional sensors 5 will be able to detect hydrocarbons that enter the annulus above the float collar 7 and will also be able to serve as backup (i.e. redundant sensors) to the sensors 5 disposed below the float collar 7.

[0016] Referring to FIG. 1, a blowout preventer 14 is disposed at the surface of the earth 3 beneath the drill rig 9 and is coupled to the tubular 4. A riser (not shown) couples the blowout preventer to the drill rig 9. The blowout preventer 14 acts as a valve to close on command from a drilling operator to prevent hydrocarbons released into the annulus from flowing improperly via the riser to the drilling rig 9.

[0017] Referring to FIGS. 1 and 2, a fiber optic cable 15 communicates measurement data from the plurality of sensors 5 to the drilling rig 9. The fiber optic cable 15 runs through

the blowout preventer 14 to the drilling rig 9. It can be appreciated that other types of communications media can be used such as electrical cables. More than one fiber optic cable 15 or communication medium may be used to provide redundancy. In one or more embodiments, a separate fiber optic cable 15 is coupled to each group of sensors 5 in a certain depth range such that if one group of sensors 5 and associated fiber optic cable 15 is damaged, then other groups of sensors 5 will still be functional and able to communicate. At the drilling rig 9, the measurement data is received and decoded by a receiver 10. In one or more embodiments, a wireless transponder 20 located at an entrance to the wellbore 2 communicates the measurement data wirelessly (e.g., using acoustic signals) to the receiver 10. From the receiver 10, the measurement data can be displayed to a drilling operator using an indicator 11 or the measurement data can be further processed by a computer processing system 12. The computer processing system 12 can be configured to receive measurements from the plurality of sensors 5 and determine if hydrocarbon leakage from a reservoir is present using one or more algorithms. The computer processing system includes a display 13 for providing output to the drilling operator. In one or more embodiments, the receiver 10 or the computer processing system 12 can provide an alarm to the drilling operator if hydrocarbons are detected in the annulus. In one or more embodiments, the computer processing system 12 can calculate a first derivative or a second derivative of a sensed parameter over time to determine if hydrocarbon leakage is stable or accelerating. Upon receipt of an indication of hydrocarbon leakage into the annulus, the drilling operator can take preventive or remedial actions such as closing the blowout preventer 14 and/or ceasing cement pumping operations. In one or more embodiments, the computer processing system 12 can be configured to automatically actuate the blowout preventer 14 or stop cement pumping operations.

[0018] It can be appreciated that one or more of the sensors 5 can be integrated into the fiber optic cable 15. For example, one or more of the sensors 5 can include fiber Bragg gratings etched into an optical fiber in the fiber optic cable 15 where a spacing of the gratings is responsive to a parameter being sensed. It can be appreciated that one or more of the sensors 5 can provide an optical output signal via a fiber optic that can be spliced to the fiber optic cable 8.

[0019] In general, the receiver 10 and the computer processing system 12 are located in a safe area 17 (shown in FIG. 1) away from industrial machinery. One example of the safe area 17 is a cabin used for activities such mud logging, measurement-while-drilling, and

logging-while-drilling. One or more indicators 11 can be located in other locations on the drilling rig 9 such as in a control room from the which the blowout preventer 14 can be actuated or cement pumping operations controlled. From the receiver 10, the measurement data can be forwarded to another location remote to the drilling rig 9 where the data can be input to Monitoring Equipment (ME) or reviewed by an observer.

[0020] It can be appreciated that disposing the plurality of sensors 5 from the distal end of the tubular 4 towards the entrance of the wellbore 2 can increase the probability of detecting hydrocarbons entering the annulus during the cementing operations and increase an amount of time that drill operators have to react to this situation. The increase in probability results from being able to detect hydrocarbons in the annulus along a range of depths at which the sensors 5 are disposed and from some of the sensors 5 being able to act as backup to other sensors 5 should the other sensors 5 fail. Hence, the plurality of sensors 5 distributed in the annulus along depths of the wellbore 4 serve to decrease a loss of hydrocarbons.

[0021] One or more of the sensors 5, such as chemical sensors, may require electrical power to operate. For the sensors 5 requiring electrical power, a battery 30 is provided in the annulus adjacent to or in the vicinity of those sensors 5 as shown in FIG. 2. The battery 5 is generally electrically insulated from the tubular 4. One or more batteries 30 can be provided for each of those sensors 5 requiring power or one battery 30 can be used to supply power to more than one sensor 5. Referring to FIG. 3, the battery 30 includes a plurality of electrodes 31. The plurality of electrodes 31 is configured to be immersed in an annulus fluid 32 that is present in the annulus. The annulus fluid 32 acts an electrolyte to generate a direct-current (DC) voltage at the plurality of electrodes based on wet battery technology principles. Materials for the plurality of electrodes 31 include those materials used in standard wet battery technology. Portions of the plurality of electrodes 31 may be embedded in a non-conductive material, which is configured to allow the annulus fluid 32 to flow to and contact the non-embedded portions of the electrodes 31. A voltage/current regulator 33 coupled to the plurality of electrodes 31 is configured to provide a regulated output to power one or more of the sensors 5.

[0022] It can be appreciated that an amount of power generated or stored in the battery 30 is dependent on the electrolyte (i.e., the annulus fluid 32). Hence, the battery 30 can be used as one or more of the sensors 5. When used as one or more of the sensors 5, the battery 30 is configured to provide an output voltage from the plurality of electrodes 31 that is related to electrolyte properties of the annulus fluid. The battery (sensor) 30 can be tested

with various hydrocarbons expected downhole to produce hydrocarbon reference data. The output of the battery (sensor) 30 downhole can then be compared to the hydrocarbon reference data to detect the presence of hydrocarbons. In addition, variations in the output of the battery (sensor) 30, reflecting variations in electrolytes in the battery 30, can be used as an indicator to detect the presence of hydrocarbons flowing or channeling through cement in the annulus during the cementing process.

[0023] In one or more embodiments, the battery 30 can be positioned in one or multiple windows cut in the tubular 4. A non-conductive composite material can provide the required mechanical and pressure strength as well as sealing area for the window(s) cut in the tubular 4.

[0024] FIG. 4 presents one example of a method 40 for completion of a well. The method 40 calls for (step 41) disposing a tubular into a wellbore penetrating the earth, an annulus region being defined between an exterior surface of the tubular and a wall of the wellbore. Further, the method 40 calls for (step 42) disposing a plurality of sensors in the annulus region, the plurality of sensors being configured to sense hydrocarbons. The plurality of sensors is further configured to sense hydrocarbons during the cementing process. That is, the plurality of sensors have the necessary design, ruggedness and robustness to withstand being immersed in wet cement while still being able to function to detect hydrocarbons flowing through the wet cement. Further, the method 40 calls for (step 43) receiving sensing data from the plurality of sensors using a receiver disposed remote to the wellbore. Further, the method 40 calls for (step 44) using the sensing data to provide an indication with an indicator or display coupled to the receiver to indicate if hydrocarbons are sensed in the annulus region.

[0025] In support of the teachings herein, various analysis components may be used, including a digital and/or an analog system. For example, the receiver 10, the computer processing system 12, the wireless transponder 20, or one or more of the sensors 5 may include the digital and/or analog system. The system may have components such as a processor, storage media, memory, input, output, communications link (wired, wireless, pulsed mud, optical or other), user interfaces, software programs, signal processors (digital or analog) and other such components (such as resistors, capacitors, inductors and others) to provide for operation and analyses of the apparatus and methods disclosed herein in any of several manners well-appreciated in the art. It is considered that these teachings may be, but need not be, implemented in conjunction with a set of computer executable instructions

stored on a non-transitory computer readable medium, including memory (ROMs, RAMs), optical (CD-ROMs), or magnetic (disks, hard drives), or any other type that when executed causes a computer to implement the method of the present invention. These instructions may provide for equipment operation, control, data collection and analysis and other functions deemed relevant by a system designer, owner, user or other such personnel, in addition to the functions described in this disclosure.

[0026] Further, various other components may be included and called upon for providing for aspects of the teachings herein. For example, a power supply (e.g., at least one of a generator, a remote supply and a battery), magnet, electromagnet, sensor, electrode, transmitter, receiver, transceiver, antenna, controller, optical unit, electrical unit or electromechanical unit may be included in support of the various aspects discussed herein or in support of other functions beyond this disclosure.

[0027] Elements of the embodiments have been introduced with either the articles “a” or “an.” The articles are intended to mean that there are one or more of the elements. The terms “including” and “having” are intended to be inclusive such that there may be additional elements other than the elements listed. The conjunction “or” when used with a list of at least two terms is intended to mean any term or combination of terms. The term “couple” relates to coupling a first device to a second device either directly or indirectly using an intermediate device.

[0028] It will be recognized that the various components or technologies may provide certain necessary or beneficial functionality or features. Accordingly, these functions and features as may be needed in support of the appended claims and variations thereof, are recognized as being inherently included as a part of the teachings herein and a part of the invention disclosed.

[0029] While the invention has been described with reference to exemplary embodiments, it will be understood that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications will be appreciated to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

What is claimed is:

1. An apparatus for completion of a well, the apparatus comprising:
a tubular configured to be disposed in a wellbore penetrating the earth, an annulus region being defined between an exterior surface of the tubular and a wall of the wellbore;
a plurality of sensors disposed in the annulus region and configured to sense hydrocarbons; and
a receiver disposed remote from the wellbore and configured to receive measurement data from the plurality of sensors and to provide an indication if hydrocarbons are sensed in the annulus region.
2. The apparatus according to claim 1, wherein the receiver is disposed at a drilling rig and the indication is provided to a drilling operator.
3. The apparatus according to claim 2, further comprising a computer processing system configured to receive the measurement data from the plurality of sensors and to determine if hydrocarbons are present in the annulus region.
4. The apparatus according to claim 3, wherein the computer processing system is configured to provide an alarm to a drilling operator upon detection of hydrocarbons in the annulus region.
5. The apparatus according to claim 2, further comprising a blowout preventer disposed at a surface of the earth and coupled to the tubular, the blowout preventer being configured to close upon receipt of a command from the drilling rig.
6. The apparatus according to claim 1, wherein the plurality of sensors are coupled to the tubular.
7. The apparatus according to claim 6, further comprising bands configured to secure the plurality of sensors to an outside surface of the tubular.
8. The apparatus according to claim 1, wherein one or more sensors in the plurality of sensors are configured to indirectly sense gas or oil by sensing temperature, pressure, or fluid density.
9. The apparatus according to claim 1, wherein one or more sensors in the plurality of sensors are configured to chemically sense gas or oil.
10. The apparatus according to claim 1, further comprising a fiber optic cable coupled to the receiver and to the plurality of sensors and configured to communicate sensor data from the plurality of sensors to the receiver.

11. The apparatus according to claim 1, further comprising a battery configured to be disposed in the annulus region, the battery comprising a plurality of electrodes configured to be immersed in a fluid disposed in the annulus region to provide an electrolyte to the battery.

12. The apparatus according to claim 10, further comprising a regulator coupled to the battery and configured to provide regulated voltage or current output.

13. The apparatus according to claim 1, wherein one or more sensors in the plurality of sensors comprises a plurality of electrodes configured to be immersed in an annulus fluid that serves as an electrolyte in order for the plurality of electrodes to generate an electrical signal responsive to the annulus fluid.

14. The apparatus according to claim 1, wherein the plurality of sensors are configured to sense a flow of hydrocarbons in wet cement during cementing of the tubular to the wellbore.

15. The apparatus according to claim 1, wherein the plurality of sensors or a subset of the plurality of sensors are disposed between a shoe disposed at a distal end of the tubular and a float collar disposed within the tubular.

16. The apparatus according to claim 1, further comprising a wireless transponder disposed at an entrance to the wellbore and configured to wirelessly communicate the measurement data from the plurality of sensors and to the receiver.

17. A method for completion of a well, the method comprising:
disposing a tubular in a wellbore penetrating the earth, an annulus region being defined between an exterior surface of the tubular and a wall of the wellbore;
disposing a plurality of sensors in the annulus region, the plurality of sensors being configured to sense hydrocarbons;
receiving sensing data from the plurality of sensors using a receiver disposed remote from the wellbore; and
using the sensing data to provide an indication with an indicator or display coupled to the receiver to indicate if hydrocarbons are sensed in the annulus region.

18. The method according to claim 17, further comprising cementing the tubular to the wellbore and sensing for the hydrocarbons during the cementing using the plurality of sensors.

19. The method according to claim 17, further comprising powering one or more sensors in the plurality of sensors using a battery comprising a plurality of electrodes configured to be immersed in an annulus fluid to provide an electrolyte to the battery.

20. The method according to claim 17, further comprising calculating a first or second derivative of an output of one or more sensors in the plurality of sensors using a computer processing system to detect a presence of hydrocarbons in the annulus region or a rate of change of hydrocarbons entering the annulus region.

21. The method according to claim 17, further comprising automatically actuating a blowout preventer upon an indication of hydrocarbons being present in the annulus region.

22. A non-transitory computer-readable medium comprising computer-executable instructions for completion of a well by implementing a method comprising:

receiving outputs from a plurality of sensors configured to sense hydrocarbons and disposed in an annulus region defined by an exterior surface of a tubular disposed in a wellbore penetrating the earth and a wall of the wellbore;

detecting a presence of hydrocarbons in the annulus region using the outputs; and
providing an indication if the presence of hydrocarbons is sensed.

23. The medium according to claim 22, wherein the plurality of sensors sense for the presence of hydrocarbons in the annulus region during cementing of the tubular to the wall of the wellbore.

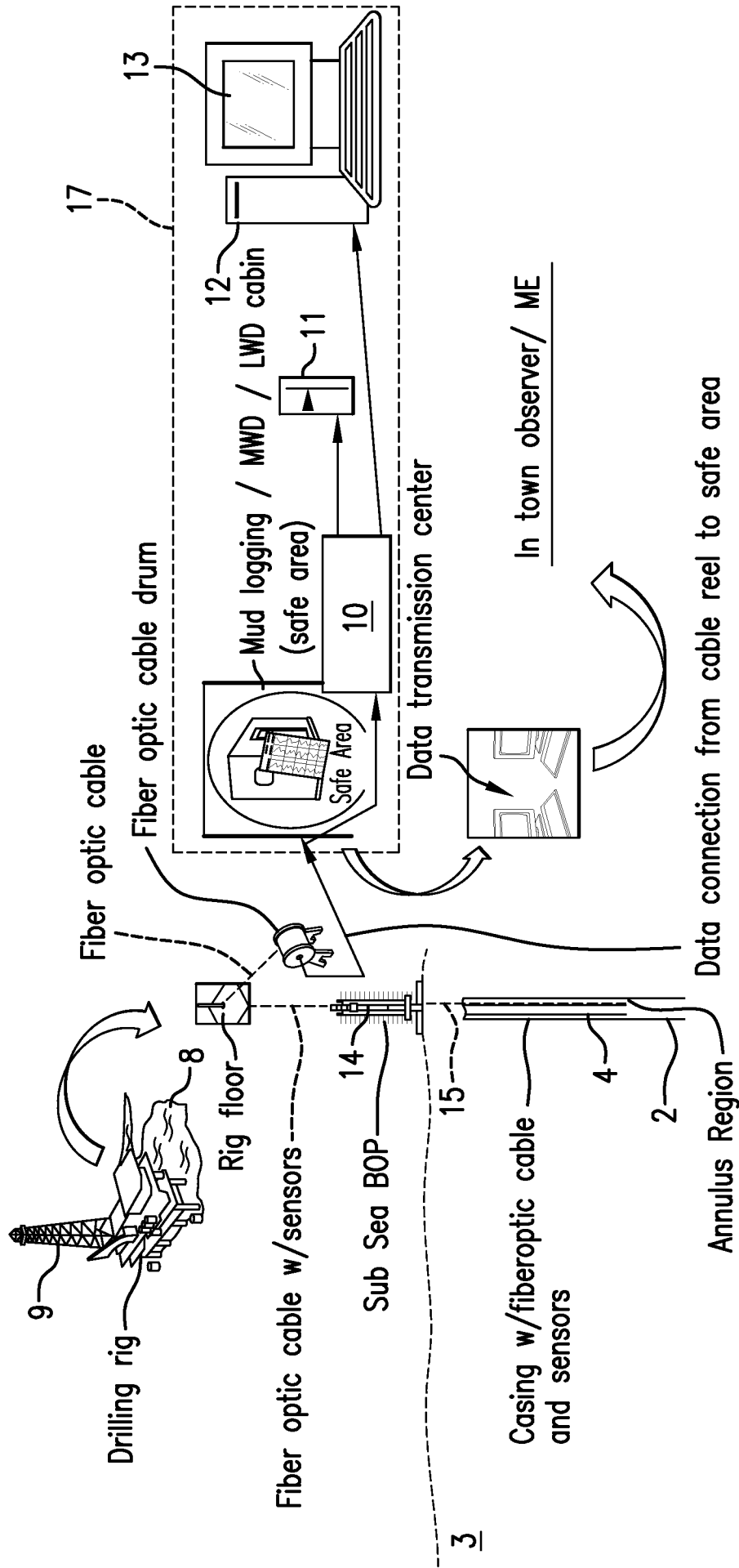


FIG.1

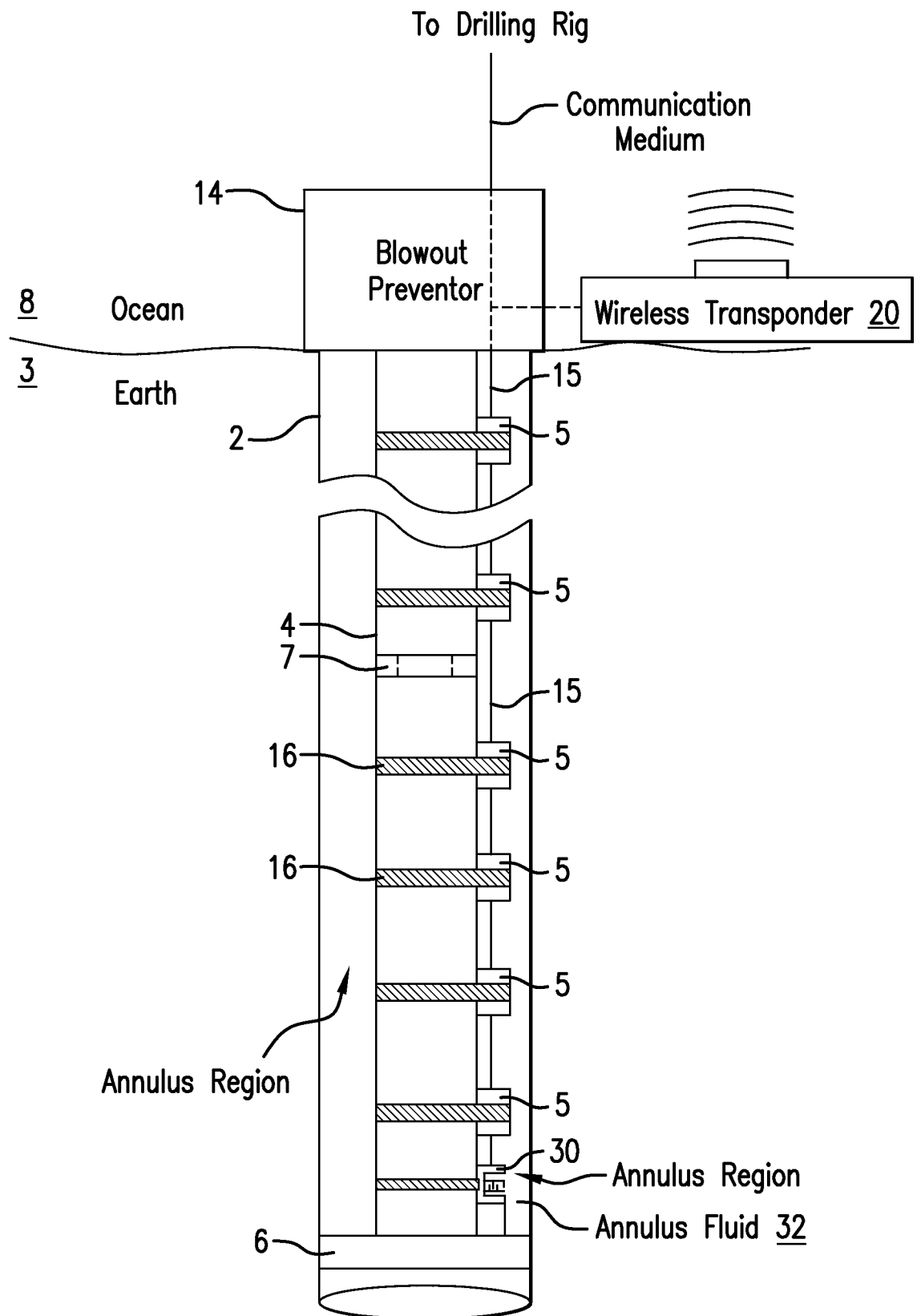


FIG.2

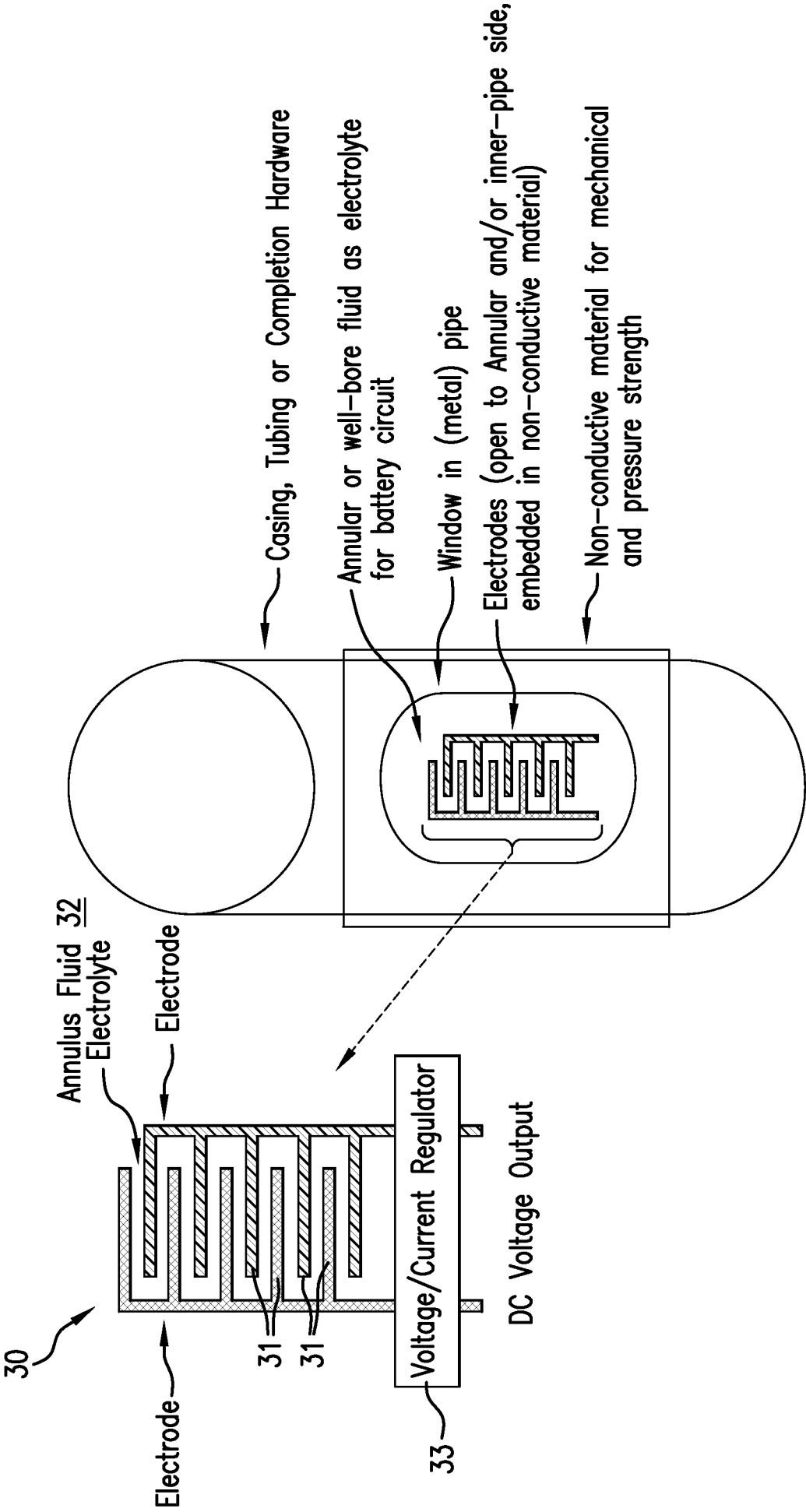


FIG.3

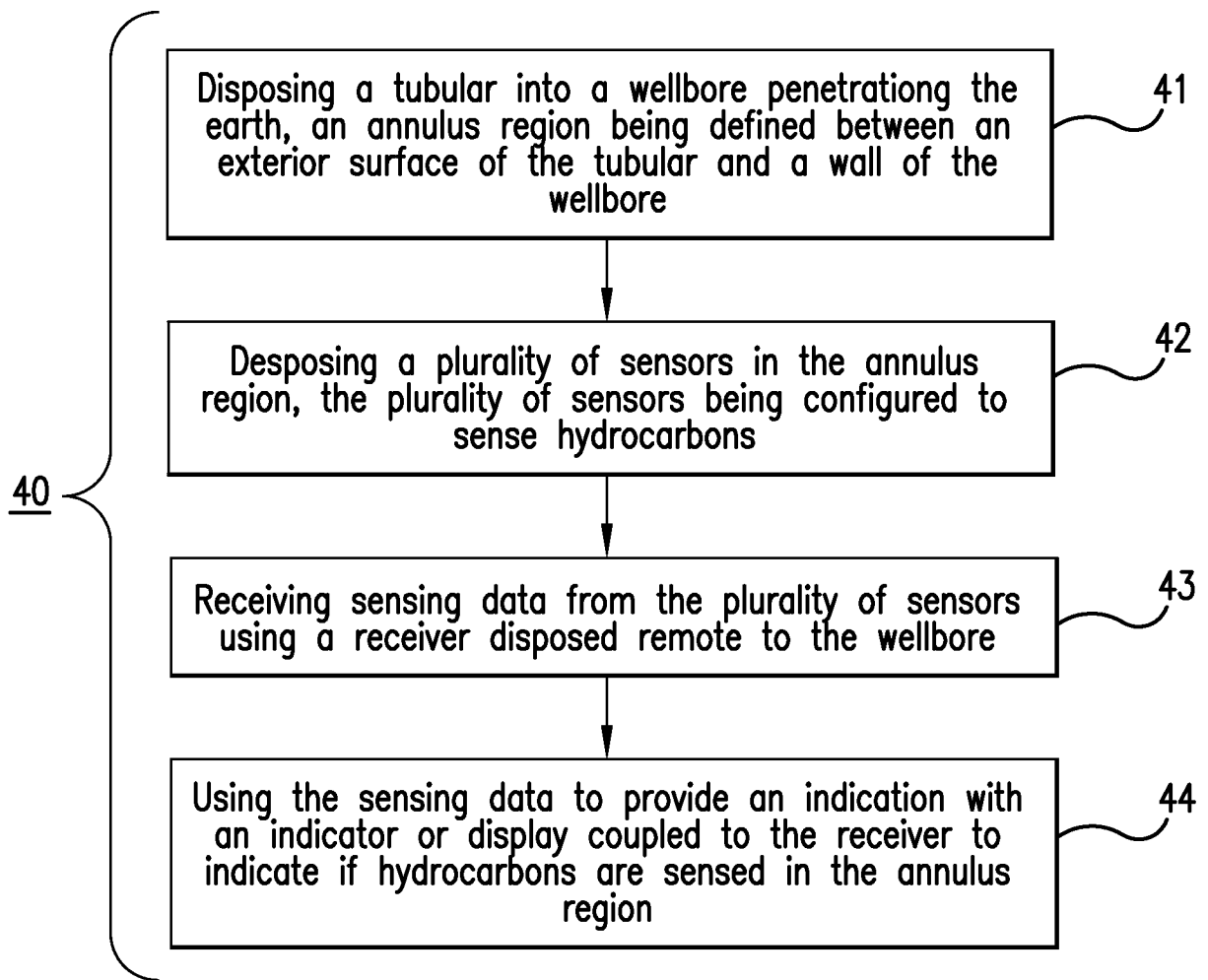


FIG.4