Title: SENSORS IN SWELLABLE MATERIALS

Abstract: A downhole equipment includes a tubing configured for deployment in a wellbore; and a measurement unit disposed on outside of the tubing, wherein the measurement unit comprises a detector embedded in a swellable material. A method for formation property measurement includes deploying a downhole equipment to a predetermined location inside a wellbore, wherein the downhole equipment comprising a tubing and a measurement unit dispose on outside of the tubing, wherein the measurement unit comprises a detector embedded in a swellable material; allowing the swellable material to swell; and performing measurements.
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SENSORS IN SWELLABLE MATERIALS

CROSS REFERENCE

This application claims the benefit of U.S. National Application Serial No. 12/823,302, entitled, "SENSORS IN SWELLABLE MATERIALS," filed on June 25, 2010, which is incorporated herein by reference in its entirety.

BACKGROUND OF INVENTION

Field of the Invention

[0001] The invention relates generally to devices and methods used in a wellbore operation.

Background Art

[0002] During production of hydrocarbons from earth formations, it is important to monitor and control the production on a regular or permanent basis to prevent any potential problems and to determine the causes of any problem (e.g., stoppage or reduction in production) in order to attempt to provide a remedy. For example, the positions of the contact surface between oil and water, and between oil and gas, within the reservoir should be monitored to prevent water or gas from mixing in the oil production.

[0003] Traditionally, measurement devices/sensors may be placed in the wellbore to perform continuous monitoring or measurements of reservoir conditions. For example, resistivity may be measured by measuring the potential difference between a measurement electrode and a reference electrode. These devices or sensors would be disposed outside a casing in a production well. These devices or sensors may be connected via contact pieces and wirings to electronic means or equipment uphole. The wirings are also disposed on the outside of the casing. These devices are typically fixed
in the wellbore when cement is injected to fill the annular space between the casing and the wellbore.

[0004] However, discontinuous cement formation may occur outside the casing due to the measurement devices located on the outside wall of the casing. As a result of the discontinuous cementing in the annulus, fluids from the rock formation may infiltrate between the cemented annulus and the casing, causing damages to the casing and the measurement devices. Furthermore, such discontinuous cementing may also create a path that can cause such fluids to rise towards the surface, thereby not only causing damages to the equipment, but also endangering personnel in the vicinity of the well.

[0005] One approach to address this issue is described in U.S. Patent No. U.S. 7,071,696, issued to Gambier et al. For example, FIG. 1 shows the outside wall (jacket) 17 of a casing contains a succession of segments having measurement devices 10. The jacket 17 of the casing provides annular recesses suitable for receiving measurement electrodes 6. The recesses are of dimensions that the electrodes 6 are no more than flush relative to the outside diameter of the jacket 17. The electrodes 6 are installed in the recesses prior to the device being lowered down the well. At least one of the devices 10 has measurement electrodes 6, and each of the devices 10 also has an axial recess for receiving a wire connection 7, which transmits the data received by the electrodes 6 to means 16 located on the surface for processing the measurements and for supplying power.

[0006] By placing the measurement devices in the recesses, these devices may not create physical obstruction on the surface of the casing, thus, avoiding discontinuous cementing. As a result, the integrity of the cemented annulus 15 may be preserved, preventing the fluids from the reservoir 13 or from the formations 12 from infiltrating between the annulus 15 and the casing. The permanently fixed measurement means, which are located on the recesses of the casing, would be protected from the fluid-induced damages.

[0007] While the methods known in the art are useful, sometimes it is desirable to have the sensors contacting a wellbore wall. Therefore, there is still a need for improved sensor deployment in the wellbores.
SUMMARY OF INVENTION

[0008] One aspect of the invention relates to downhole equipment. A downhole equipment in accordance with one embodiment of the invention includes a tubing configured for deployment in a wellbore; and a measurement unit disposed on outside of the tubing, wherein the measurement unit comprises a detector embedded in a swellable material.

[0009] Another aspect of the invention relates to methods for formation property measurements. A method in accordance with one embodiment of the invention includes deploying a downhole equipment to a predetermined location inside a wellbore, wherein the downhole equipment comprising a tubing and a measurement unit disposed on outside of the tubing, wherein the measurement unit comprises a detector embedded in a swellable material; allowing the swellable material to swell; and performing measurements.

[0010] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0011] FIG. 1 shows an example of a prior art downhole measurement system.

[0012] FIG. 2 shows a wellbore equipment in accordance with one embodiment of the invention prior to swelling of a swellable material.

[0013] FIG. 3 shows a wellbore equipment in accordance with one embodiment of the invention after swelling of a swellable material.

[0014] FIG. 4 shows a wellbore equipment containing measurement devices in accordance with one embodiment of the invention after swelling of the swellable materials.
FIG. 5 shows a wellbore equipment containing measurement devices in accordance with one embodiment of the invention after swelling of the swellable materials.

FIG. 6 shows a wellbore equipment containing measurement devices in accordance with one embodiment of the invention for use in intelligent completion operations.

FIG. 7 shows a wellbore equipment containing a resistivity array on a section of a tubing coated with a swellable material in accordance with one embodiment of the invention.

FIG. 8 shows an example of quadrupole electrodes that may be used in resistivity devices in accordance with one embodiment of the invention.

FIG. 9 shows an example of single electrode arrays that may be used with a resistivity device in accordance with one embodiment of the invention.

FIG. 10 shows a method for performing formation property measurements in accordance with one embodiment of the invention.

DETAILED DESCRIPTION

Embodiments of the invention relate to methods and systems for deploying sensors, measurement devices, or equipment in wellbores. These wellbore equipment, sensors, or measurement devices may be used to monitor the formation properties, the well conditions, or other production parameters. Embodiments of the invention may be used on land or off shore. For clarity of illustration, the following description uses the devices for measuring pressure and/or resistivity in the well or formation to illustrate embodiments of the invention. However, one of ordinary skill in the art would appreciate that the same approaches may be used with other kinds of sensors or devices for performing measurements on other wellbore or formation parameters, such as porosity, permeability, temperature, etc.
In accordance with embodiments of the invention, a tubing or casing for deployment downhole may include one or more measurement units, each of which may include one or more detectors or sensors embedded in a swellable material. The swellable material may be oil swellable (solvent swelling), water swellable (osmotic swelling), or oil/water swellable. The swellable material compositions may be those known in the art, including rubbers and elastomers. Rubbers may be natural or synthetic rubbers. Elastomers may include those listed in ASTM D1418. In addition, a swellable material may be a mixture that includes a filler, plasticizer, accelerator, fiber, nanoflake and/or nanoplatelet, as long as the material retains the swellability.

Preferably, the swellable materials would swell, but do not substantially degrade or disintegrate upon long term exposure to the downhole conditions or downhole fluids, e.g., water and water-based fluids, such as brines, or hydrocarbons. Preferably, swelling maintains the basic material properties and the cross-links in the molecular structures of the swellable materials, thereby maintaining the positive swelling pressure for a period of time.

By using swellable materials, embodiments of the invention can be deployed, before swelling, in a wellbore with relative ease and with less danger of damages to the sensors or devices because the tubings (or casings) with the attached measurement units have diameters smaller than the diameters of wellbores. Once the tubings with the measurement units are in position, the swellable materials may be allowed to swell. Once the swellable materials expand, they help to place the detectors or sensors in positions. This is particularly advantageous when the sensors or detectors need to be in contact with the wall of a wellbore. For example, for measurements of formation pressures and permeability, it would be necessary to press the pressure sensors against the wall of the wellbore. Even with other measurements where the sensors do not need to contact the formation, it might still be advantageous to put the sensors closer to the formations. For sensors that need to contact the formations, the sensors are embedded in a manner that the contact sides of the sensors are exposed, i.e., not embedded in the swellable materials.
In accordance with some embodiments of the invention, the sensors or measurement devices embedded in a swellable material may be used by themselves without additional cementing. Yet, in accordance with other embodiments of the invention, cementing may be used in conjunction with the swellable materials. The following describes several examples to illustrate embodiments of the invention. One skilled in the art would appreciate that these examples are not meant to limit the scope of the invention and that various modifications or variations of these examples are possible without departing from the scope of the invention.

Sensors Embedded in a Swellable Material for Measuring Pressure

FIG. 2 illustrates one embodiment of the invention. As shown, a measurement unit 20 (e.g., a pressure sensor) in accordance with one embodiment of the invention is disposed on the outside of a tubing or casing 26, and the tubing is deployed to a desired location in a wellbore 22 penetrating a formation 24. As shown in this example, the tubing or casing 26 includes retention elements 28 on the outside of the casing for retaining the measurement unit 20, which includes a pressure probe 21 embedded in a swellable material 23. Thus, the measurement unit 20 may be deployed in the wellbore 22 when the tubing or casing 26 is run in the wellbore 22.

As shown in this example, the measurement unit 20 includes a pressure probe 21 connected to a pressure gauge 29, which is connected to a downhole electrical cable 25. The electrical cable 25 may supply the power and/or transmit the pressure measurements from the measurement device 20 to the surface for processing.

The system shown in FIG. 2 can be run in the wellbore before the swellable material is allowed to expand. Once the measurement device is deployed at the desired depth, the swellable material may be allowed to swell and expand. FIG. 3 shows the measurement unit 20 of FIG. 2 after the swellable material 23 has expanded. The swellable materials 23 expands after being exposed to a swelling fluid, which may be water, water-based fluids, hydrocarbons, or water-hydrocarbon mix fluids. When the swelling material 23 absorbs the swelling fluids, the swelling material 23 may expand to
press against the wall of wellbore 22 and create an annular seal 30 inside the wellbore 22. As a result, the pressure probe 21 is urged against the formation 24 to facilitate formation pressure measurements.

[0029] Note that the expanded swelling material 23 may form a tight seal around the annulus, this tight seal may prevent fluids from flowing into different zones in the well. In addition, these tight seals may also help to fix the tubing or casing 26 in the wellbore. Therefore, cementing may become optional. However, in some cases, cementing may still be performed to secure the structure of the well.

[0030] Although the examples shown in FIG. 2 and FIG. 3 include only one sensor device, one skilled in the art would appreciate that embodiments of the invention may involve more than one sensor devices. For example, FIG. 4 shows another example in accordance with embodiments of the present invention. As shown, a tubing or casing 40 may contain a series of pressure measurement units (or pressure substations) 42, 42' (two are shown here for illustration), which may be located in tandem or in any spacing configurations on the outside of the tubing or casing 40. Each measurement unit 42, 42' may contain a pressure probes 44, 44'. These probes 44, 44' may be embedded in a swellable material 48, 48' and held by retaining elements 46, 46'. The probes 44, 44' may be connected to pressure gauges 45, 45', which may be connected to a downhole electrical cable 47.

[0031] In some embodiments, the pressure gauges 45, 45' and/or part of the cable 47 may be also embedded in the swellable material 48, 48'. The cable 47 may supply the power and/or transmit the pressure data from the devices 42, 42' to the surface for processing.

[0032] After the devices 42, 42' are exposed to swelling fluids, such as water, water-based, and/or oil fluids, the swellable material 48, 48' may expand to press against the formation 49 and create pressure-holding annular seals inside the wellbore 43. The swelling of the swellable materials may urge the pressure probes 44, 44' against the formation 49 to facilitate the pressure measurements.

[0033] The systems illustrated in FIG. 3 and FIG. 4 may be instrument liners or tubings that are not intended to be cemented in the wellbore. On the other hand, some instrument
strings (liners) may be intended to be used with cementing. Such liners may be made up of multiple sections of tubings. The joints of these sections of tubings may be protected with cross coupling protectors. Once such liners are deployed in a well, the liners may be cemented in the well. Embodiments of the invention can also be used with these liners. In these cases, the swellable materials and sensors may be conveniently included on the outside of the liner in between the cross coupling protectors. In this manner, the cross coupling protectors may also help to protect the measurement units during deployment.

For example, FIG. 5 shows an example in accordance with embodiments of the present invention. As shown, a typical tubing or liner 50 is made up of multiple sections of tubings. The joints of the sections are protected by cross coupling protectors 52, 52', and 52" (three are shown here for illustration). Three pressure measurement units (or subs) 54, 54', 54" are shown positioned on the outside of the tubing or liner 50. Each pressure measurement subs 54, 54', 54" may contain a reservoir pressure probe 56, 56', 56" connected to a pressure gauge 55, 55', 55". In some embodiments, both the probe 56, 56', 56" and the gauges 55, 55', 55" may be embedded in a swellable material 58, 58', 58". In other embodiments, the gauges 55, 55', 55" may be outside the swellable material 58, 58', 58". The probes 56, 56', 56" and the gauges 55, 55', 55" may be connected to a downhole electrical cable 57, which may supply the power and/or transmit the pressure data obtained from the devices 54, 54', 54" to the surface for processing.

After the swellable materials 58, 58', 58" are exposed to a swelling fluid, such as water, water-based, and/or oil fluids, the swellable material 58, 58', 58" would expand to push against the formation 59 to create pressure-holding seals within the wellbore 53. As a result, the flexible probes 56, 56', 56" may be pressed against the formation 59 for performing pressure measurements.

Embodiments of the invention can be advantageously used in intelligent completion (IC) applications. In intelligent completion (IC) applications, pressure sensors and resistivity sensors are deployed in the well to monitor the conditions of the well in various zones and to maximize the production. For example, FIG. 6 shows an exemplary intelligent completion string 60 that may include a series (only two shown for
illustration) of flow control valves 64, 64', swellable packers 69, 69', and pressure measurement subs 66, 66' for monitoring formation pressures. The pressure measurement subs may comprise pressure sensors embedded in swellable materials, as described above. Thus, once the IC string 60 is in place and the swellable materials expand, the sensors will be urged against the formation for monitoring the formation pressures. Similarly, the sensors may include resistivity or other type of sensors for monitoring or measuring other formation properties.

Sensors Embedded in Swellable Material for Measuring Resistivity

Although the above description uses pressure sensors to illustrate embodiments of the invention, one skilled in the art would appreciate that embodiments of the invention may use other types of sensors, such as resistivity sensors. For example, FIG. 7 shows a resistivity array 70 in accordance with one embodiment of the invention. The resistivity array 70 may contain any numbers of resistivity subs 71 disposed on a string, interspersed with a swellable material 72. The resistivity subs 71 may be connected by an electric cable 73, which may be embedded in the swellable material 72.

The swellable material 72 in the embodiment shown in FIG. 7 may be coated on a casing or liner 74 and may function as insulators for the resistivity sensors (e.g., electrodes). In addition, the swellable material 72 may replace cements for zonal isolation in a well. When the cable 73 is embedded in the swellable material 72, the swellable material 72 also helps to protect the cable 73.

The resistivity subs 71 may contain any suitable number or types of resistivity sensors/detectors, e.g., electrodes or coils (antennas). For example, FIG. 8 shows an example of a resistivity array 80, in which each resistivity sub comprises four electrodes 81 in a quadrupole electrode configuration. In contrast, FIG. 9 shows an example of a resistivity array 90, in which each resistivity sub includes a single electrode 91. These are examples for illustration only. One skilled in the art would appreciate that other configurations may also be used without departing from the scope of the invention. Furthermore, while the examples use electrodes as resistivity sensors/detectors, embodiments of the invention include those using electromagnetic (EM) coils (antennas)
or combinations of electrodes and antennas. When EM coils are used, they may be longitudinal magnetic dipole (LMD) or transverse (or tilt) magnetic dipole (TMD) coils.

[0040] Although the above examples describe the use of pressure sensors and resistivity sensors with swellable materials, modern intelligent well completion may employ various downhole sensors, including seismic or acoustic sensors, pressure sensors, resistivity sensors, temperature sensors, flow-rate sensors/gauges, gamma ray detectors, optical sensors, pH sensors, vibration sensors, chemical composition sensors, water or gas cut rate meters, mechanical stress sensors, radioactive tracer sensors, etc. Embodiments of the invention may be used with any of these devices or a combination thereof.

[0041] Embodiments of the present invention may be used with or without cementing after the wellbore equipment is deployed to a predetermined location inside the wellbores and swelling materials have expanded. Thus, if desired, the casing or the liner may still be cemented in place using conventional methods, such as stage cementing techniques.

[0042] Some embodiments of the invention relate to methods for using an equipment or system of the invention in a wellbore. For example, FIG. 10 shows a method 100 for deploying a wellbore equipment inside a wellbore in accordance with one embodiment of the present invention. The wellbore equipment carrying measurement units (subs), some or all of which may be embedded in a swellable material on the outside wall of a casing or a liner, may be deployed to a predetermined location inside a wellbore (step 102). Once the measurement device reaches the predetermined location, a swelling fluid, such as water, water-based, oil, and/or water/oil fluids, may be used to swell the swellable material or the swellable material may be allowed to contact a wellbore fluid to expand (step 104). Thus, the swellable material may expand and press against the formation to create pressure-holding annular seals inside the wellbore. As a result, the measurement devices may be urged against the formation to contact with the formation (step 106). The measurement devices may then be used to perform measurements related to the formation properties, such as pressure, resistivity, porosity, permeability, pH, temperature, etc. (step 108).
Advantages of embodiments of the invention may include one or more of the following. By embedding the measurement devices in a swellable material, the probes, the cables, the gauges, the casing and/or the liner may be protected from damages during run-in of the casing or liner. In addition, the measurement devices may be brought into contact with the formation by the swelling material, thus, providing more accurate measurements. While the sensors that need to be in contact with the formation would benefit most from embodiments of the invention, even sensors that do not need to be in contact with the formation would benefit from the approach disclosed herein. For example, when these sensors are deployed in a state embedded in a swellable material, they are less likely to be damaged during deployment. In addition, when the swellable material expands, these sensors would be placed closer to the formation. Even if direct contact is not required, many sensors benefit from being in closer proximity to the formation to be measured.

Furthermore, compared with methods using cement to permanently fix the measurement devices in place, the devices and methods in accordance with the embodiments of the invention can provide a less labor intensive (thus, cheaper), faster, and safer way to deploy the sensors and to perform measurements or monitoring. For example, the expanded swellable materials can seal the wellbore into different zones, thereby functioning as inflatable packers. In some situations, the swellable materials when expanded can provide seals and support such that cementing may not be needed.

While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.
CLAIMS

1. A downhole equipment, comprising:
   a tubing configured for deployment in a wellbore; and
   a measurement unit disposed on outside of the tubing,
   wherein the measurement unit comprises a detector embedded in a swellable material.

2. The downhole equipment of claim 1, wherein the swellable material is a swellable rubber.

3. The downhole equipment of claim 1, wherein the detector is a pressure measurement device.

4. The downhole equipment of claim 3, wherein the pressure measurement device comprises at least one flexible pressure probe.

5. The downhole equipment of claim 1, wherein the tubing is made up of a plurality of sections and comprises cross coupling protectors to protect joints between the plurality of sections.

6. The downhole equipment of claim 5, wherein the measurement unit is disposed between the cross coupling protectors.

7. The downhole equipment of claim 1, wherein the detector is a resistivity measurement device.

8. The downhole equipment of claim 7, wherein the resistivity measurement device comprises one or more electrodes.

9. The downhole equipment of claim 7, wherein the resistivity measurement device comprises one or more electromagnetic coils.
10. The downhole equipment of claim 1, wherein the measurement unit is a resistivity array comprising a plurality of electrodes.

11. The downhole equipment of claim 10, wherein the plurality of electrodes are separated by the swellable material disposed on the outside of the tubing.

12. A method for formation property measurement, comprising:
   deploying a downhole equipment to a predetermined location inside a wellbore,
   wherein the downhole equipment comprising a tubing and a measurement unit dispose on outside of the tubing, wherein the measurement unit comprises a detector embedded in a swellable material;
   allowing the swellable material to swell; and
   performing measurements.

13. The method of claim 12, wherein the allowing the swellable material to swell results in pushing the detector to contact a wall of the wellbore.

14. The method of claim 12, wherein allowing the swellable material to swell results in a hydraulic isolation along the outer diameter of the tubing.

15. The method of claim 12, wherein the swellable material is a swellable rubber.

16. The method of claim 12, wherein the detector is a pressure measurement device.

17. The method of claim 12, wherein the detector is a resistivity measurement device.

18. The method of claim 17, wherein the resistivity measurement device comprises a resistivity array having a plurality of electrodes separated by the swellable material disposed on the outside of the tubing.

19. The method of claim 12, wherein the measurement unit comprises a pressure measurement device and a resistivity measurement device.
20. The method of claim 12, wherein the detector is at least one member selected from the group consisting of: acoustic measurement devices, temperature measurement devices, vibration measurement devices, chemical composition measurement devices, water or gas cut measurement devices, flow rate measurement devices, mechanical stress measurement devices, and radioactive tracer measurement devices.
FIG. 10

100 Deploy a wellbore equipment to a predetermined location inside a wellbore

102

104 Allow the swellable material to swell

106 Contact the measurement device with the wellbore

108 Perform a measurement