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Hartsell

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[54] **METHOD FOR DETECTING ENTRY OF A LOW HYDROGEN CONTENT GAS INTO BOREHOLE FORMATIONS**

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[51] **Int. Cl.** **G01v 5/00**

[58] **Field of Search** 250/259, 260, 253, 255, 250/269

[56] **References Cited**

UNITED STATES PATENTS

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[57] **ABSTRACT**

The method of detecting the point of entry of a gas into a producing well, which comprises the steps of first measuring the hydrogen content of the hydrocarbon products native to the formations in correlation with depth, then injecting a gas having less hydrogen content than said hydrocarbon products into the formations surrounding the well, then measuring the hydrogen content of the hydrocarbon products within the well and surrounding formations in correlation with depth after said gas has been injected, and comparing said first and second named measurements to determine the location of the point of entry of said gas into said well as indicated by a reduction in the hydrogen content of said second measurement relative to said first measurement at the same depth.

6 Claims, 3 Drawing Figures

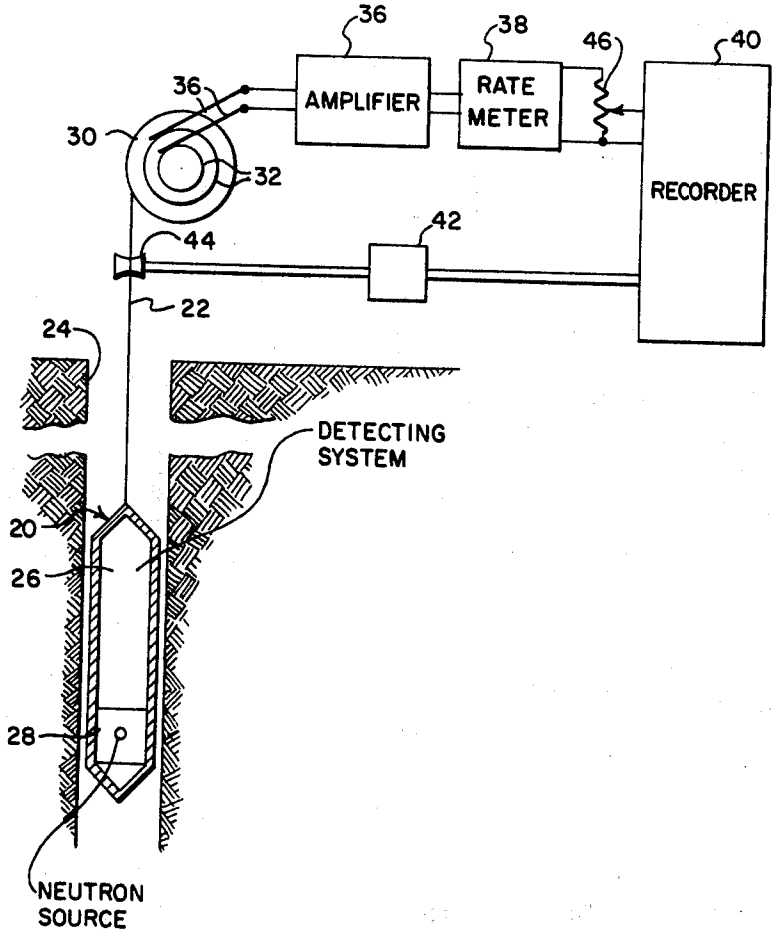


FIG. 2

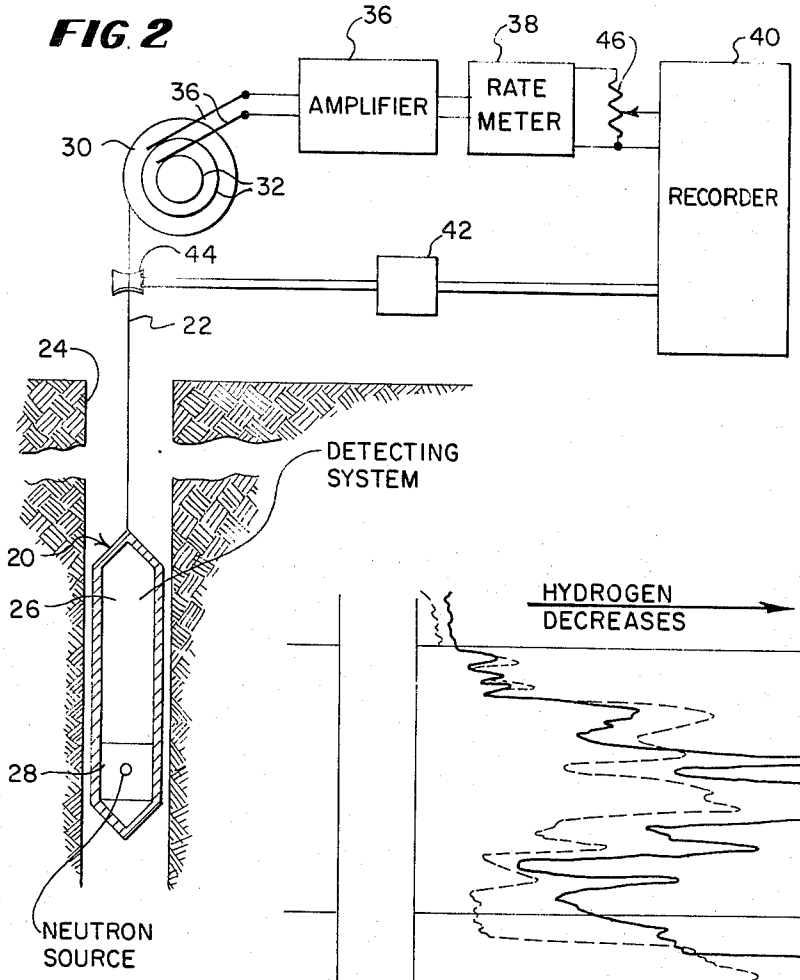


FIG. 1

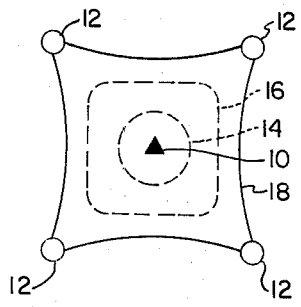
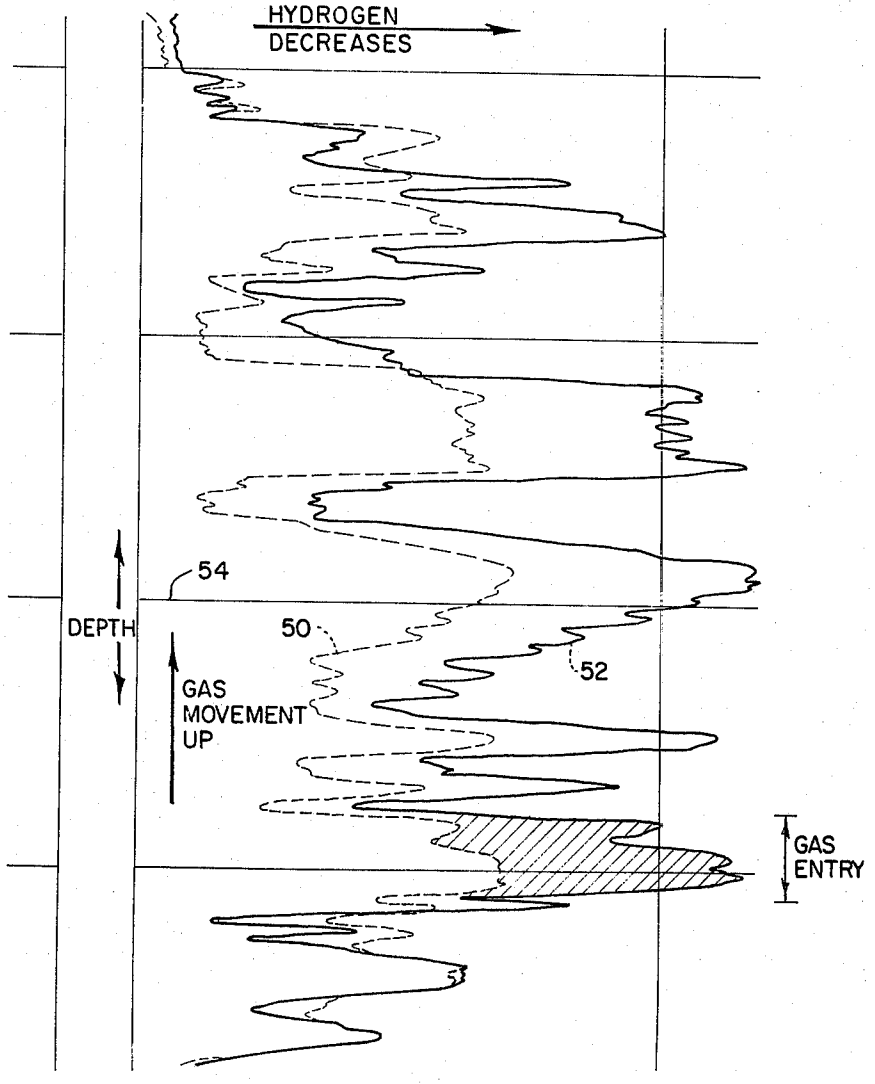


FIG. 3



METHOD FOR DETECTING ENTRY OF A LOW HYDROGEN CONTENT GAS INTO BOREHOLE FORMATIONS

The present invention relates to secondary recovery operations for the recovery of oil from oil wells which have become naturally depleted or to increase the production from oil wells whose efficiency is low under normal depletion conditions. Specifically, the present invention relates to an improved method for detecting the entry of a low hydrogen content gas into the formations adjacent a producing well.

In the secondary recovery field of oil well operations, a number of methods have become popular to enhance the recovery of oil from a flowing well whose productivity is low. These methods include water flooding, gas injection, thermal methods and miscible-phase flooding. In water flooding and gas injection methods, a fluid such as gas or water is forced into the producing formation by means of a centrally located injection or inlet well and the injected fluid tends to flush the oil from the rock toward the surrounding producing wells. While the leading edge of the injected fluid tends to advance in a circular pattern during the initial stages of the injection operation, during later stages the pattern becomes irregular and eventually the injected fluid will reach one of the producing wells at a projection point of the pattern while some areas of the reservoir remain full of oil. This breakthrough of the injected fluid into the producing well must then be detected and a suitable cementing, packing or flow control operation must be performed at the point of entry of the injected fluid so as to seal off this escape point for the injected fluid and permit further invasion of the injected fluid into the remaining uninjected areas.

When gas is employed as the injection fluid two survey type of measurements are normally employed to detect the entry of gas into one of the producing or flowing wells. In one such method a temperature survey is made to measure the cooling effect within the borehole from the expansion of the entering gases. According to another method, the change in density of the fluid in the borehole is measured as the injected gas, which has broken through the formations surrounding the borehole at a particular point, mixes with the borehole fluid. Both of these methods for detecting gas entry require that the injected gas must be miscible with or capable of mixing readily with the borehole fluid. Hydrocarbon gases are thus easily detected in producing wells because their entry into the borehole is not restricted by the flowing oil and they permeate the oil column easily so that they can be readily measured by the above two methods. However, when the injected gas used in the secondary recovery operation is a low hydrogen content gas, such as carbon dioxide, the breakthroughs in producing wells are difficult to locate. This is due to the resistance of the oil column within the borehole to accept the gas, thus restricting the expansion of the gas which would cause temperature changes capable of detection and diminishing the mixing of the injected gas with the fluid column to produce a detectable change in density.

It is a principal object therefore of the present invention to provide a new and improved method for detecting the entry of a low hydrogen content gas into the formations adjacent the flowing well which eliminates one

or more of the disadvantages of the prior art arrangements discussed above.

It is a further object of the present invention to provide a new and improved method for accurately detecting the breakthrough or entry point of an injected gas into a flowing well which is suitable for use in situations where the injected gas is of relatively low hydrogen content.

Briefly considered the method of the present invention comprises the steps of first measuring the hydrogen content of the hydrocarbon products within the well in correlation with depth. This may be conveniently done by running a neutron log in the well at the time it is drilled or before initiating the secondary recovery operation.

A gas having less hydrogen content than the petroleum products in the formations is then injected into the formations surrounding the producing well, this being customarily done by means of a centrally located injection well. When a breakthrough of the injected gas into the area of the producing well occurs, as determined by inspection of the gas content of the flowing well at the surface, the point of entry of this breakthrough may then be located by again measuring the hydrogen content of the hydrocarbon products within the well and surrounding formations in correlation with depth and comparing the first and second measurements to determine the location of the point of entry of the injected gas into the formations as indicated by a reduction in the hydrogen content of the second measurement relative to the first measurement at the same depth.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings in which:

FIG. 1 is a diagrammatic illustration of a typical secondary recovery operation during which the method of the present invention may be employed;

FIG. 2 is a sectional view of a neutron logging system which may be employed in performing the entry detection method of the present invention; and

FIG. 3 is a composite chart of the two neutron logs made before and after entry of the injected gas, and illustrating the manner in which the exact point of entry may be accurately determined.

Referring now to the drawings, a typical secondary recovery operation is shown diagrammatically in FIG. 1 wherein a centrally located injection well **10** is positioned within a surrounding group of producing wells **12.** A fluid such as gas or water is injected into the well **12** under pressure and spreads out into the surrounding formations so that it tends to flush the oil from the rock toward the producing wells **12.** During the initial stages of the injection operation the leading edge of the injected fluid is uniform, as indicated by the circle **14.** As the injection operation continues, the pressure due to surrounding injection wells tends to flatten the leading edge pattern to the position shown at **16** in FIG. 1 and finally a cusp like pattern will be produced as indicated at **18** in which the injected fluid reaches one or more of the producing wells **12.** When the injected fluid is a gas it is necessary to seal off the breakthrough point so that other portions of the formation may continue to be flushed out. However, this requires a determination of the depth at which the breakthrough of the injected gas

has occurred. Furthermore, if the injected gas is hydrogen free or has a low hydrogen content, the conventional methods of detecting the breakthrough point which involve measurement of the temperature within the borehole to determine the point at which cooling due to expansion of the entering gases occurs, or a density measurement to determine the point at which the gas mixes with the borehole fluid, do not provide accurate results since the entering gas must be capable of mixing readily with the hydrocarbon borehole fluid.

The method of the present invention takes advantage of the fact that a neutron log is normally made at the time the well is drilled and this neutron log is run at a certain sensitivity. The sensitivity setting is usually part of the data given on the neutron log. Furthermore, the neutron log is particularly sensitive to the hydrogen content of the rock formations surrounding the borehole, and is relatively insensitive to the characteristics of the borehole fluid. Accordingly, the initial neutron log which is normally run at the time the well is drilled provides an accurate measurement of the hydrogen content of the rock formations adjacent the borehole wall before secondary recovery operations are started. However, if an initial neutron log is not available on the producing wells, such neutron logs are run in accordance with the present invention, prior to the initiation of secondary recovery operations so that this information will be available and can be used in accordance with the present invention to detect the breakthrough point of the injected gas into a producing well in an accurate manner.

After a neutron log has been run in a producing well, a gas having a relatively low hydrogen content as compared with the hydrocarbon products within the formations adjacent the producing well is injected into the surrounding formations. This gas injection step is normally accomplished by a centrally located injection well, as described generally heretofore. When a breakthrough of the injected gas into the producing well occurs a second neutron log is then run in the borehole in correlation with depth and the completed log is then correlated with the initial neutron log to determine the point of entry of the injected gas. However, in order to provide an accurate correlation, it is necessary that the second neutron log be run at the same sensitivity as the initial neutron log which was made prior to initiation of the secondary recovery operations. This may be conveniently done by an arrangement such as indicated in FIG. **2** wherein a typical neutron logging system is shown. Referring to this figure, the neutron logging system may comprise a subsurface unit **20** which is lowered by means of the cable **22** into the borehole **24.** Subsurface unit **20** comprises a detecting system **26** and a neutron source **28.** The cable **22** suspends the logging instrument in the well and contains the required conductors for electrically connecting the instrument with the surface apparatus. The cable is wound on or unwound from drum **30** in raising or lowering the instrument **20** to traverse the well.

In making a neutron log of the well, the subsurface instrument **20** is raised within the well and neutrons from the source **28** irradiate the formation surrounding the borehole and radiations as influenced by the formations are detected by the detecting system **20.** These radiations which are detected may either comprise slow neutrons or gamma rays of capture which result from the slowing down of neutrons within the formation due to interaction with hydrogen atoms therein.

The resultant signal is sent to the surface through the cable **22** and through slip rings **32** and brushes **34** on the end of the drum, the signal may be supplied to an amplifier **36** for amplification and processing, the output of the amplifier **36** being supplied to a rate meter **38** which in turn supplies this output to a suitable recorder **40.** The recorder **40** is driven through a transmission **42** by a measuring reel **44** over which the cable **22** is drawn so that recorder **40** moves in correlation with depth as the subsurface instrument **20** traverses the well.

The elements described thus far are shown diagrammatically and it is to be understood that the associated circuits and power supplies are provided in a conventional manner. Amplifier **36** may be included in the subsurface instrument, or amplification may be effected both on the surface and in the subsurface instrument. It is also to be understood that the instrument housing will be constructed to withstand the pressures and mechanical and thermal abuses encountered in logging the well and provides adequate space within it to house the necessary apparatus and permit transmission of radiation through it.

In a typical neutron logging system such as shown in FIG. **2,** it is customary to provide an arrangement whereby the sensitivity of the log may be varied so that logs may be run at the same sensitivity and compared to provide correlated information of the geological formations which have been logged. Such a sensitivity adjustment is indicated diagrammatically in FIG. **2** as the potentiometer **46** which is shown connected to the output of the rate meter **38,** the potentiometer **46** being normally adjusted during an initial calibration procedure so that a predetermined number of counts per second in the detecting system **26** provides a certain number of deflection units of the pen of the recorder **40.** A neutron calibrating system and sensitivity adjustment is shown, for example, in Scherbatskoy U.S. Pat. No. 3,038,076. However, it will be understood that any other suitable sensitivity adjusting arrangement may be employed insofar as the present invention is concerned.

Considering now the manner in which the second neutron log is run in accordance with the present invention to determine the breakthrough point of the injected gas in a producing well, the sensitivity adjustment potentiometer **46** is first adjusted so that the deflection sensitivity of the recorder **40** is exactly the same as the deflection sensitivity employed when the initial neutron log was run, either at the time the well was drilled or before secondary recovery operations are initiated. After this sensitivity adjustment has been made, the subsurface instrument **20** is then lowered within the well and a second neutron log is made in correlation with depth to permit determination of the breakthrough or entry point of the injected gas. After the second neutron log has been made, it is correlated with or compared to the initial neutron log in the manner shown in FIG. **3** of the drawings.

Referring to this figure, the initial neutron log is shown in dotted lines as the curve **50** and the second neutron log, which is made after the breakthrough of the injected gas occurs, is shown in full lines as the curve **52** in FIG. **3.** These two curves are superimposed in FIG. **3** by correlating the depth measurement lines **54** of the two logs, it being understood that the log is

usually made from the bottom of the borehole to the surface and hence the curves of FIG. 3 are shown with the greatest depth at the bottom of the correlated graphs. It will be noted from FIG. 3 that at the lowest depth shown therein the two curves **50** and **52** follow generally the same pattern indicating that the hydrogen content in this portion of the formations has not changed due to the secondary recovery operations. However at the point identified in FIG. 3 as "gas entry" it will be observed that the curve **52** is displaced substantially to the right as compared to the curve **50.** This displacement of the curve **52** to the right corresponds to a marked decrease in hydrogen content in the formations at that particular depth. Since the injected gas has been chosen to be of relatively low hydrogen content it will be evident that the marked disparity between the two curves **50** and **52** is due to the entry of the injected gas into the formations at the depth indicated in FIG. **3.** In this connection it will be understood that if the injected gas has a relatively high hydrogen content, then the two curves **50** and **52** will not diverge appreciably since the displacing injected gas functions to provide substantially the same neutron logging signal as the hydrocarbon products which it displaces. Preferably, the injected gas employed in accordance with the present invention is either a hydrogen free gas such as carbon dioxide, or the gas of low hydrogen content such as propane, butane or the like. In any event, the injected gas should have a lower hydrogen content than the hydrocarbon products in the formations initially logged in order that the above-described divergence between the curves **50** and **52** will be achieved.

It will also be noted from FIG. **3** that the curves **50** and **52** continue to be relatively widely displaced from one another all the way up to the top of the portion of the log shown in FIG. **3,** but then the curves cease to diverge appreciably. This is due to the fact that the logs shown in FIG. **3** were actually made in a well in which tubing extended down into a portion of the casing within the borehole. The depth to which the tubing extends is indicated as the point at which the curves come back together since the second log has decreased sensitivity when the radiations have to pass through both the tubing and the casing. However, it will be understood that a suitable divergence between logs may be obtained through both tubing and casing providing the sensitivity for both the initial and second logs are increased correspondingly. It will also be understood that the method of the present invention may be used with increased boreholes as well as wells where casing has been set, it being only necessary to correlate the sensitivity of the two logs so that the above-discussed divergence effect will be achieved. In this connection it will be noted that the sensitivity of the neutron logs **50** and **52** is such that the curves are responsive to the hydrogen content of the hydrocarbon products native to the rock formations as well as the characteristics of the borehole fluid. Accordingly, it is not necessary for the injected gas to be completely mixed with the borehole fluid to be detected in accordance with the method of the present invention.

It will also be understood that the method of the present invention may also be used for tracer surveys in petroleum wells, by injecting a low hydrogen content gas into the well and following movement of the injected gas by means of the above-described neutron logging techniques. Thus, by comparing the neutron log made after injection of the gas with an initial neutron log made before gas injection an indication can be obtained of the nature of the surrounding formations, in a manner similar to techniques conventionally employed with radioactive tracers, and the like.

While there have been illustrated and described various embodiments of the present invention, it will be apparent that various changes and modifications thereof will occur to those skilled in the art. It is intended in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the present invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a secondary recovery system of the type in which gas is injected into the formation and forces oil into one or more adjacent producing wells, the method of detecting the entry of the injected gas into one of the producing wells which comprises the steps of, injecting into the formations at a point removed from one of the producing wells a gas having less hydrogen content than the hydrocarbon products native to the formations adjacent said one of the producing wells, obtaining an initial neutron log of said producing well prior to the entry of said injected gas into said producing well, obtaining a second neutron log of said producing well after the entry of said injected gas into said producing well, and comparing said initial neutron log and said second neutron log to determine the point of entry of said injected gas.

2. The method of claim **1** wherein said point of entry of said injected gas is determined in accordance with the displacement of said second neutron log relative to said initial neutron log.

3. The method of claim **1,** wherein the portions of the borehole in which said injected gas is present correspond to relatively low hydrogen content displacements of said second log relative to said initial log.

4. The method of claim **1,** wherein said initial neutron log and said second neutron log are both run at the same sensitivity.

5. The method of claim **1** wherein said injected gas is carbon dioxide.

6. The method of detecting the point of entry of a gas into a producing well, which comprises the steps of first measuring the hydrogen content of the hydrocarbon products native to the formations surrounding said well in correlation with depth, then injecting a gas having less hydrogen content than said hydrocarbon products into the formations surrounding the well by introduction of said gas at a point removed from said producing well, then measuring the hydrogen content of the hydrocarbon products within the well and surrounding formations in correlation with depth after said gas has been injected, and comparing said first and second named measurements to determine the location of the point of entry of said gas into said well as indicated by a reduction in the hydrogen content of said second measurement relative to said first measurement at the same depth.

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