Aug. 2, 1960 E. F. EGAN ET AL 2,947,869

METHOD OF STUDYING SUBSURFACE FORMATIONS

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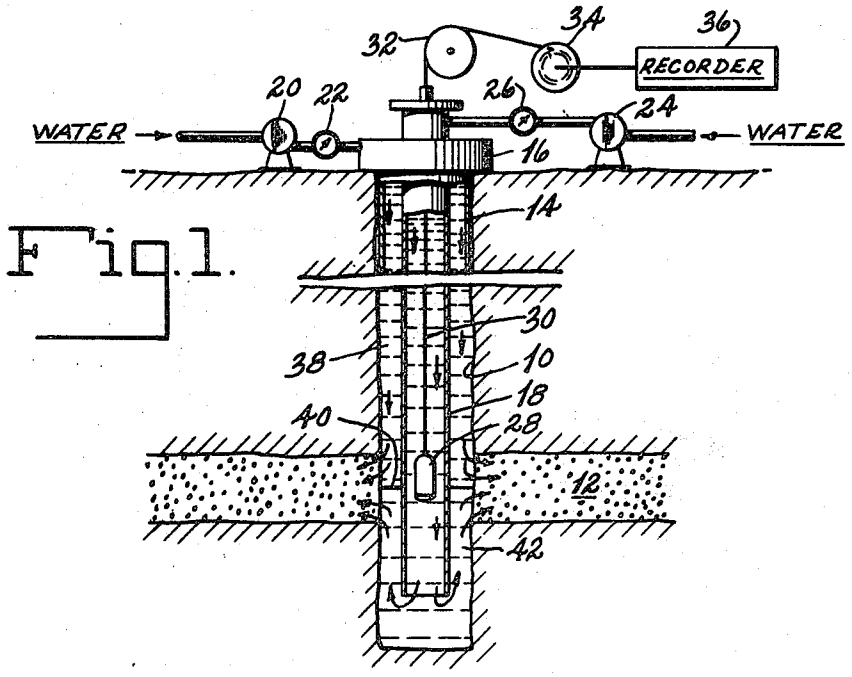

Fig. 1.

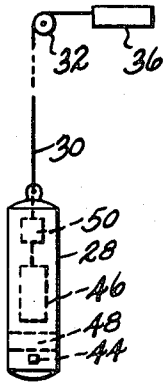

Fig. 2.

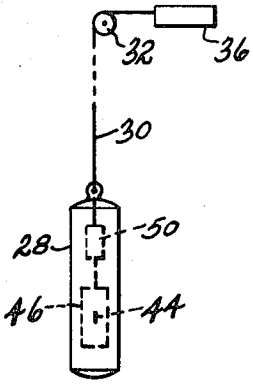

Fig. 3.

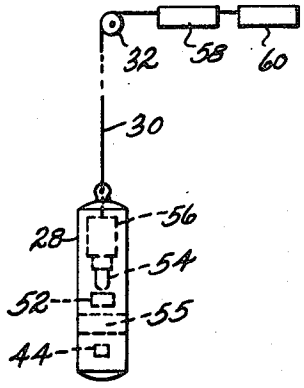

Fig. 4.

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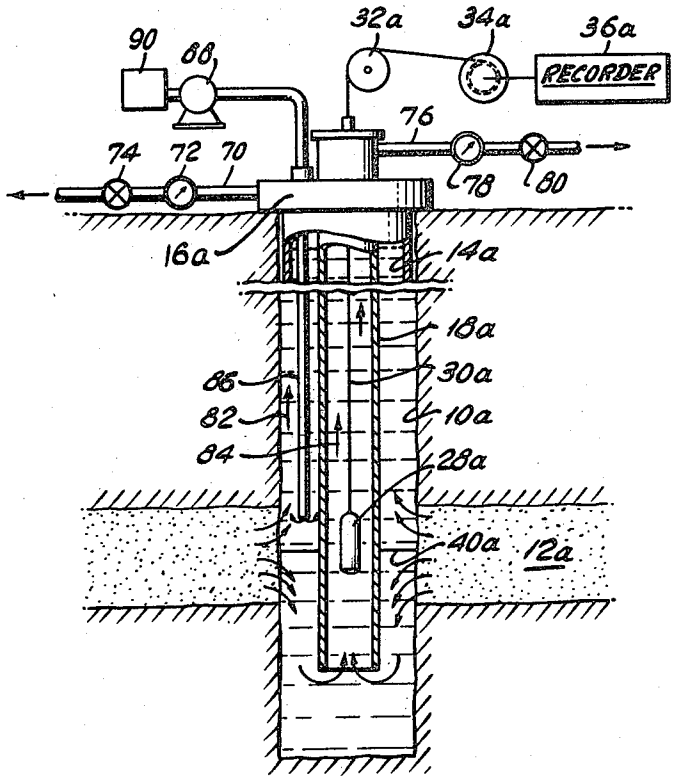
Fig. 5.



United States Patent Office 2,947,869
Patented Aug. 2, 1960

2,947,869

METHOD OF STUDYING SUBSURFACE FORMATIONS

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Filed Oct. 22, 1954, Ser. No. 463,998

14 Claims. (Cl. 250—43.5)

This invention relates to a method of studying subsurface earth formations and more particularly to a method of measuring the permeability of vertical sections of a permeable earth formation traversed by a well or borehole and through which formation fluid is either being pumped for secondary recovery or "water flooding" purposes or from which formation fluid is flowing into the borehole. The principal purpose of the invention is the provision of a method of this type by means of which accurate measurements can be made and without the use of any radioactive fluid in the borehole or any other fluid which might contaminate or do any other lasting damage to the formations traversed by the well.

This application is a continuation-in-part of our pending application, Serial No. 349,817, filed April 20, 1953, now abandoned.

The importance of secondary recovery or repressuring in oil fields has increased greatly during the last few years, and there is consequently a real need for a better understanding of the engineering aspects of these projects. Detailed studies of reservoir performance of water flooding conditions can be undertaken only when certain basic data are available, and among the data which is necessary is information concerning the vertical distribution of the injected water in a water injection well.

In an application, Serial No. 349,784, filed April 20, 1953, now abandoned, in the name of Edmond F. Egan and Gerhard Herzog, a method is disclosed for making an "injection profile" of a permeable formation traversed by a borehole. In the method disclosed in that application, two similar fluids such as water are pumped down in the well, one of these liquids being pumped down through a string of tubing to a point below the formation to be examined, while the other liquid is pumped down through the annular space between the tubing and the casing or the walls of the hole. One of these liquids, preferably that which is pumped down through the annular space between the tubing and the walls of the hole, is made radioactive by the addition of a small amount of a radioactive substance, while the other liquid which is pumped down through the tubing is non-radioactive. These liquids will meet somewhere in the annulus above the lower end of the tubing and an interface will exist at that point. The depth of this interface will depend upon the rates of injection of the two liquids, and the interface can be caused to move up or down through the annular space around the tubing by varying these rates of injection. The position or depth of the interface is located by passing a radiation detector through the tubing and noting the change in the response of the detector as it passes from the radioactive liquid into the non-radioactive liquid or vice versa. The sum of the rates of injection of the two liquids is maintained constant and, as stated above, by increasing the rate of injection of the radioactive liquid while decreasing the rate of injection of the non-radioactive liquid, the interface can be made to move downwardly through the hole past the exposed walls or surface of the formation to be examined. By adjusting these rates of injection in increments while metering the injection fluid and noting the depth of the interface after each change, one can determine the amount of the radioactive liquid which is passing into the increment of the formation between adjustments.

This invention is in some respects similar to the invention described in the above-mentioned Egan and Herzog application but does not necessitate the use of a fluid which has been made radioactive. As stated above, the method to be described can be used on water injection wells to determine the amount of water passing into various depth increments of an exposed permeable formation. Two similar fluids are pumped into the borehole, one of these fluids being pumped down through a string of tubing extending to a point below the permeable formation while the other fluid is pumped down through the annulus or the annular space between the tubing and the casing or walls of the bore hole. The sum of the injection rates of the two fluids is held constant and the ratio of the rates of injection of the two fluids is adjusted or changed by predetermined increments. As the rate of injection of one fluid is increased with respect to the rate of injection of the other fluid, the interface between the two fluids will move upward or downward in the borehole, depending upon which fluid has its rate of injection increased. After each adjustment of the ratio of the two injection rates, the location of the interface is found in a manner which will be described hereinafter.

The fluid to be injected into the formation usually consists of salt water, and it is desirable to differentiate between salt water which has traveled down the tubing and that which passes downwardly through the outer annular space around the tubing without changing the flow properties of the salt water through the porous media. This is done in accordance with the present invention by dissolving a small amount of a neutron-reactive substance, such as a lithium, cadmium, chlorine or boron containing material, e.g., boric acid, in the water stream flowing downwardly in the annulus. It is possible to detect the presence of these materials by using effects which depend upon the much greater capture cross section of these materials for thermal neutrons than is the case for the nuclei of other substances such as hydrogen, oxygen, or chlorine which are ordinarily present in the salt water.

As another embodiment of the invention a method will be described for determining the amount of fluid which enters a borehole at any given depth. In this method which is somewhat similar to, but in some respects the reverse of the injectivity method which has been described, it is assumed that the borehole traverses a producing formation, i.e., a formation from which a fluid or fluids such as oil, water, or gas is, or are, flowing into the borehole and that it is desired to know the amounts of fluid or fluids which flow into the borehole from different sections of the formation.

In this embodiment which will be described hereinafter, the borehole is provided with a string of tubing extending downwardly at least to the bottom of the producing formation. The flow rates of the fluids passing upwardly through both the tubing and the annulus, i.e., the annular space between the tubing and the casing or the walls of the hole are controlled so that there will be some depth in the zone of interest, i.e., the annular space between the tubing and the walls of the producing formation at which the fluid flow divides. This point or depth may be called a "null point." All fluid above the null point will flow upwardly in the annulus and all fluid below the null point will flow downwardly into the lower end of the tubing and then upwardly to the surface. The position of this null point or interface can be moved up or down along the wall of the formation by varying the flow rates of the two fluids flowing upwardly. It is to be understood

that one fluid only, for example, oil, may be flowing into the borehole from the producing formation of interest or that different fluids such, for example, as oil and gas, water and oil, or the like may be flowing from the formation into the borehole, gas, for example, flowing into the hole from a particular section or sections of the formation while oil flows into the hole from another section or sections. This is to be taken into consideration where reference is made hereinafter to the "two fluids" flowing upwardly, one through the tubing and the other through the annulus. In other words, it is to be understood that these fluids may be the same, i.e., both fluids may be oil but flowing into the hole at different rates from different sections of the formation, or that the fluid flowing upwardly through the tubing may be, say, oil while the fluid flowing upwardly through the annulus may be gas.

For a better understanding of the invention, reference may be had to the accompanying drawing in which:

Fig. 1 is a vertical sectional elevation through a portion of a borehole traversing a permeable formation or zone into which it is desired to inject a fluid such as salt water;

Figs. 2, 3, and 4 are somewhat diagrammatic illustrations of instruments which can be used for locating the interface between the two fluids which are pumped into the well, and

Fig. 5 is a view similar to Fig. 1 but showing the borehole as traversing a "producing" formation.

Referring to the drawing, and particularly to Fig. 1, a borehole 10 is shown as traversing a permeable formation 12 into which it may be desired to inject a fluid. The upper portion of the borehole is shown as lined with a casing 14 having a closed casing head 16 at the surface and a string of tubing 18 extends downwardly into the borehole to a depth below the formation 12. A pump 20 is shown as connected to the casing head 16 through a suitable meter 22 and a second pump 24 is shown as connected to the upper end of the tubing 18 through a similar meter 26.

A detecting device 28 is shown as suspended within the casing 18 on the lower end of a conductor cable 30. This cable passes over a suitable cable-measuring device 32 which is adapted to measure continuously the length of the cable payed out, and thus the depth of the instrument 28 in the borehole. The cable may then pass over a suitable hoisting device or reel 34 connected electrically with a recorder 36 which may also contain means for amplifying the signals from the instrument 28.

A fluid 38 such as salt water containing a small amount of boric acid or other neutron-reactive substance is forced by the pump 20 through the meter 22 and downwardly in the borehole through the annulus or annular space between the tubing 18 and the walls of the hole. Salt water 42 without the neutron-reactive substance is simultaneously forced by the pump 24 through the meter 26 and downwardly through the tubing 18 until it passes out of the bottom of the tubing and then upwardly where an interface 40 will exist between the two bodies or streams of salt water. The sum of the rates of injection by the two pumps 20 and 24 is held constant, but the ratio of the two rates of injection is varied or adjusted by increments. An increase in the rate of pumping the fluid 38 with a decrease in the rate of pumping the fluid 42 will cause the interface 40 to move downwardly in the hole.

The instrument 28 which is used for detecting and locating the depth of the interface 40 may take one of several slightly different forms. In any case the instrument comprises a sealed housing 28 which contains a source of neutrons such as a mixture of radium and beryllium from which neutrons will pass outwardly in all directions. In the embodiment illustrated in Fig. 2, a thermal neutron detector 46 such, for example, as a proportional counter filled with boron trifluoride is disposed within the housing 28 in spaced relation to the source 42. The detector may, if desired, be separated from the source by a shield 48 which may comprise a layer of paraffin for slowing down the neutrons passing generally upwardly from the source 44, a layer of a material such as cadmium capable of absorbing the slow neutrons and an upper layer of lead capable of absorbing gamma rays originating in the source and which otherwise would pass upwardly to strike the detector 46. The housing 28 may also contain a suitable preamplifier 50 for amplifying the output of the detector 46 before it passes to the lower end of the cable 30. It is desirable to have the neutron detector 46 placed in such a position relative to the source 44 that the detector response is comparatively insensitive to changes in the hydrogen content of the surrounding materials. Thus, the sensitive volume of the detector should lie approximately from 2 to 6 inches from the source. Due to boron's high capture cross section for slow neutrons, the response of the detector 46 will be lower when the instrument 28 is surrounded by a boron-containing fluid than when the instrument is surrounded by the salt water containing no boron. It will be seen, therefore, that when the instrument 28 is lowered through the tubing 18, it will at first be surrounded by the boron-containing salt water 38, and the recorder 36 will register a certain detector response. When, however, the instrument passes farther downwardly so that it is surrounded by the salt water 42 which contains no boron, the detector response will be higher and there will, therefore, be a rather sudden change in the recorded thermal neutron intensity as the instrument passes the interface 40, and the depth of the instrument 28 in the hole at that time as measured by the device 32 will be indicative of the depth of the interface 40 in the hole.

In operation, the pump 20 is at first stopped so that all of the fluid being pumped will be that passing downwardly through the tubing 18. This fluid 42 will force any boron-containing fluid opposite the walls of the formation 12 into that formation, and the interface 40 will remain opposite the upper boundary of that formation. Pump 20 will then be started to pump a predetermined amount of the boron-containing water into the annulus, and at the same time the pump 24 will be slowed down by a like amount. This will cause the interface 40 to move downwardly along the exposed surface of the formation 12 to a new position, and the instrument 28 will be passed through the tubing to locate the new position or depth of the interface, as has been described hereinbefore. The ratio of the rates of pumping by the two pumps 20 and 24 will continue to be adjusted by increments, and the interface 40 will move downwardly to a new position after each adjustment. The instrument 28 will be passed through the tubing after each adjustment to locate accurately the depth of the interface at the new position. The percentage of water passing into any increment of the formation 12 will be equal to the rate of the injection of the boron-containing water 38 at the new location of the interface minus the rate of injection of the boron-containing water at the previous location times 100 divided by the total or sum of the rates of injection of the water 38 and the water 42. In this manner, an "injectivity profile" can be made showing the amount of water which will pass into the various vertical sections of the formation 12.

In Fig. 3 is shown a slightly different form of the measuring instrument 28. In this case, the neutron source is disposed on the axis of the detector 46. The output of the detector passes through a preamplifier 50 and then upwardly to a recorder 36, as has been described.

In Fig. 4 is shown another embodiment of the detecting instrument 28, and in this case a neutron source 44 is separated from a scintillation detector having a thalium-activated sodium iodide crystal 52 and a photomultiplier tube 54, the output of which is preamplified at 56 and passed upwardly through the cable 30. In this case the scintillation crystal 52 should be separated from the neutron source 44 by several inches of dense gamma ray shielding material 55 such as lead. With this spac-

ing, changes in the detector response will not depend strongly on the hydrogen content of the surrounding formation. In this case the cable **30** passes over the measuring device **32**, then to a discriminator **58** which in turn is connected to a recorder **60**. Use is made of the proportionality between the size of the pulses from the photomultiplier **54** and the energy of the gamma rays which impinge on the crystal **52** and the discriminator bias will be set to cut out the small pulses which are caused by scattered gamma rays striking the crystal and the thermal neutron induced gamma rays from the boron. When the annular space is filled with ordinary salt water, the induced gamma rays will generally have energies from 2.2 up to 8 mev. as the thermal neutrons are captured by hydrogen, chlorine and iron nuclei. However, when an appreciable amount of the thermal neutrons are captured by the boron nuclei in the boron-containing salt water **38**, the number of high energy induced gamma rays will be decreased, and the counting rate or response of the detector will also decrease. The depth of the interface **40** can therefore be located by noting a sudden increase or decrease in the output of the detector.

It is also contemplated that a substantially gamma ray-free neutron source such as a mixture of polonium and beryllium could be used, this source being shielded by a dense material such as tungsten. One would then observe the presence of boron directly. A differential pulse height analyzer could be used to accept pulses of about 0.5 mev. gamma rays which are emitted when the boron nuclei capture thermal neutrons.

The method which has been described for making water injection profiles has the following distinct advantages. The detecting instrument can be passed through the tubing, and there will therefore be no instrument in the annular space around the tubing to disturb the interface which is to be located. The small amount of boron used will not appreciably change the chemical behavior of the water, and this is a very important consideration if the formation contains clays which will swell if contacted by fresh water. The two fluids are completely miscible so there will be no relative permeability effects to be taken into consideration. The method can be used either in open hole or in a hole provided with a casing which has been perforated. No knowledge of variations in borehole diameter is required. It is not necessary to use any radioactive water which might be considered to have a health hazard.

Although in the description of the method which has been given, it has been stated that the interface **40** is moved downwardly in increments along the walls of the formation **12**, it is to be understood that the permeability log of the formation can be made upwardly as well as downwardly. Thus, the interface **40** can be positioned first at or just below the lower boundary of the formation **12** and then the pumping rates of the two liquids changed by decreasing the rate of pumping at **20** and increasing the rate at **24**, by the same amount of course, so that the interface will move upwardly to a new position along the wall of the formation. This new position or depth of the interface will then be found, as has been described, by moving the instrument **28** through the tubing and these operations may be repeated until the interface has reached a point above the upper boundary of the formation. The resulting log obtained in this manner will be the same as a log obtained by moving the interface downwardly.

Although the neutron reactive liquid **38** has been described as being pumped down through the annulus and the salt water **42** through the tubing, it is to be understood that the paths of these liquids can be reversed, i.e., the neutron reactive liquid can be pumped down through the tubing and the salt water through the annulus without affecting the process.

As has been described in the aforementioned Egan-Herzog patent application, the present method of providing an interface between two liquids and then locating and following this interface as it moves past formations of different permeability can be used for other purposes such as the location of leaks in the well casing. One can also detect and locate leaks around the casing shoe on water injection wells, and this is an important consideration when old oil wells are converted to water injection wells. The method can also be used in selective acidizing, i.e., where it is desired to inject an acid into an oil-containing section other than into a gas or water-containing section of a formation. Additional uses of the method are for selective squeeze cementing, locating a zone of lost circulation, and formation fracturing operations.

In connection with the selective acidizing mentioned above, the neutron-reactive material could be omitted and the interface between fresh water and hydrochloric acid located directly because of the fairly large neutron capture cross section of the chlorine in the acid. One could also use salt water and fresh water as the two fluids for certain applications, providing the denser salt water is used as the lower fluid **42**.

While one application of this method has been described with reference to the forcing of acid into a formation or into a certain portion of a formation, it is to be understood that, if desired, almost any material can be placed in a similar manner. For example, a material such as a plastic or other substance which will affect the surface tension can be pumped into a formation or portion of so as to increase or decrease the permeability, if desired.

Although the apparatus illustrated in Fig. 1 of the drawing shows the use of two pumps, one to pump the neutron reactive liquid and the other to pump the plain salt water, it is to be understood that a single pump can be utilized, the output stream from the pump being divided by a suitable arrangement of piping and valves and each divided stream being provided with a suitable meter such as **22** or **24**. The neutron reactive material can, of course, be injected into the desired one of the streams.

The log or record of the output of the neutron instrument **28** will also show the presence of joints in the tubing **18**, and this can be of assistance in checking the depth of the instrument in the hole when the length of the tubing sections are known.

As mentioned hereinbefore, it may be desired to determine the amounts of fluid or fluids entering the borehole at a given depth or depths or to determine the relative rates of the flow of fluid into the hole through adjacent vertical sections of the wall of the formation. Fig. 5 illustrates this method and it will be observed that the apparatus shown is quite similar to that disclosed in Fig. 1.

In Fig. 5 the bore hole is indicated at **10*a***, a producing formation at **12*a*** and a casing in the upper portion of the hole at **14*a***. The casing head **16*a*** supports a string of tubing **18*a*** extending downwardly to or slightly below the lower boundary of the formation of interest **12*a***. An outlet pipe **70** is connected through the casing head to the annular space between the tubing **18*a*** and the casing **14*a***, and this pipe contains a flow meter **72** and a flow controlling valve **74**. Likewise an outlet pipe **76** is connected to the interior of the tubing **18*a*** and contains a flow meter **78** and a flow-controlling valve **80**. The valves **74** and **80** control respectively the flow rates of the fluid **82** flowing upwardly through the annulus between the tubing **18*a*** and the wall of the borehole and the fluid **84** flowing upwardly through the tubing **18*a***. Under these conditions there will be some depth in the annular space between the tubing **18*a*** and the wall of the formation **12*a*** at which the flow of fluid entering the borehole divides. Thus, the fluid **82** is shown as entering the hole through an upper section of the formation **12*a*** and the fluid **84** as entering the hole from a lower section. A "null point" or interface **40*a*** will thus exist at this depth and

this null point can be moved up or down along the wall of formation 12*a* by changing the flow rates of the fluids 82 and 84 while maintaining constant the sum of the flow rates of the two fluids. Thus, merely by way of illustration, the valves 74 and 80 may be first adjusted so that the flow rate of the fluid 82 is 10 gallons per minute while the flow rate of the fluid 84 is 20 gallons a minute. It is assumed that with these flow rates the interface or null point 40*a* will be in the position indicated in Fig. 5. By again adjusting the valves 74 and 80, the flow rate of fluid 82 may be increased to 12 gallons per minute while the flow rate of the fluid 84 may be decreased to 18 gallons per minute. The total flow rate will remain at 30 gallons per minute but null point 40*a* will move downwardly to a somewhat lower position or depth opposite the wall of the formation 12*a*. By repeating these operations and measuring the distance moved by the null point for each adjustment of the two flow rates information will be obtained as to the relative amounts of the flow of fluids into the borehole from different vertical sections of the formation 12*a* in substantially the same manner as the log of permeability is made by means of the injectivity method which has been described and illustrated in Fig. 1 of the drawing.

In the method of measuring the flow rates of the fluids into the borehole it is of course necessary to locate the depth or position of the null point 40*a* for each ratio of flow rates as controlled by the valves 74 and 80. It is contemplated that the null point 40*a* can be located in any suitable manner as by injecting a tracer into the fluid as it enters the borehole and then noting whether or not this tracer passes upwardly to the surface with the fluid 82 or with the fluid 84. While several forms of tracers may be used, it is preferred that the tracer be a neutron-reactive substance such as a solution of a boron compound, for example, borax or boric acid and that this material be injected into the fluid in a suitable manner such as from the lower end of a string of small tubing, pipe, or hose such as the "macaroni" string 86. This string of small tubing is shown as extending downwardly through the casing head 16*a* and the annular space between the tubing 18*a* and the walls of the bore hole. The upper end of the tubing 86 may be connected to a suitable pump 88 receiving a supply of boron-containing solution from a small tank 90.

Shown as suspended within the tubing 18*a* is an instrument 28*a* corresponding to the instrument 28 of Fig. 1 and which may be similar to any one of the embodiments illustrated in Figs. 2, 3, and 4 of the drawing; thus this instrument may, for example, contain a small source of neutrons, a detector of secondary radiation such as scattered neutrons and a preamplifier, the output of which is led to the surface through the cable 30*a* and recorded at 36*a*.

With the lower end of the small tubing 86 and the detecting instrument 28*a* positioned about as illustrated in Fig. 5, i.e., the lower end of the tubing 86 being disposed above the null point 40*a*; the boron compound being injected into the fluid above this null point will flow upwardly with the fluid 82. Although the detecting instrument 28*a* is shown more or less opposite the lower end of the tubing 86, the detector will have a rather high response since many of the neutrons from the source will be scattered in the liquid 84 within the tubing 18*a* and back to the detector within the instrument. In other words, the presence of the boron in the fluid outside the tubing 18*a* will have very little effect. However, if then the tubing 86 is lowered so that its lower end is below the null point 40*a*, the boron will no longer pass upwardly with the fluid 82 but rather will pass downwardly and into the tubing 18*a* with the fluid 84. The detector then being surrounded with a boron fluid will show a considerably lower response due to the absorptive effect of the boron on the neutrons. By raising and lowering the small tubing 86 by increments and by observing the response of the detector after each movement, the exact position of the null point 40*a* can be determined. It will be observed that this method of locating the null point or interface is similar to that previously described with reference to the location of the interface 40 of Fig. 1, the only real difference being that the tracer or neutron reactive material is injected into the well fluid at a point opposite the walls of the formation 12*a* rather than at the surface.

If desired, the neutron source and detector or, in other words the instrument 28*a* may be disposed at the surface either in the fluid flow from the pipe 70 or the pipe 76. In such a case however there will be a certain lag in response since when the lower end of the tubing 86 passes the null point 40*a* the tracer will shift from the fluid 82 to the fluid 84 or vice versa and since there will be considerable fluid both within the tubing 18*a* and within the annulus it may be some time before this fluid passes the detector at the surface. It is preferred therefore that the instrument 28*a* be suspended within the tubing 18*a* at a point more or less opposite the lower end of the small tubing 86.

As stated hereinabove, it is to be understood that other tracer materials may be used and the depth of null point 40*a* located in different ways than that which has been described. It will be observed that in the foregoing specification methods have been described in which a determination may be made of the relative rates of the flow of fluid or fluids through different sections of the wall of a borehole traversing a zone of interest, either when the fluid is being pumped into a formation or when it is flowing from a formation into the borehole.

Obviously many other modifications and variations of the invention, as hereinbefore set forth, may be made without departing from the spirit and scope thereof, but only such limitations should be imposed as are indicated in the appended claims.

We claim:

1. The method of making a permeability log of a subsurface formation traversed by a borehole which comprises pumping a fluid into said borehole above said formation, simultaneously pumping a similar fluid into said borehole below said formation, one of said fluids containing a neutron-reactive substance, thereby establishing an interface between said fluids, determining the depth in the hole of said interface by determining the response of the fluids in the hole to neutron bombardment, varying the ratio of the pumping rates of the two fluids being pumped into the hole while maintaining constant the sum of the two fluids so as to cause said interface to move along the walls of said formation to a new position, determining the depth of the interface at said new position in a similar manner, and repeating these operations while noting the ratios of the two fluids being pumped for each measured depth of the interface in the hole.

2. The method of making a permeability log of a subsurface formation traversed by a borehole which comprises pumping a liquid into said borehole above said formation, said liquid containing a small amount of a neutron-reactive substance, simultaneously pumping a similar liquid free from said neutron-reactive substance into said borehole below said formation, thereby establishing an interface between said liquids, determining the depth in the hole of said interface by measuring the content of said substance in the liquid throughout that portion of the hole being examined, varying the ratio of the pumping rates of the two liquids while maintaining constant the sum of the two liquids being pumped so as to cause said interface to move along the walls of said formation to a new position, determining the depth of the interface at said new position by making another measurement of the content of said substance in the hole, and repeating these operations while noting the ratios of the

two liquids being pumped for each measured depth of the interface in the hole.

3. The method as described in claim 1 in which the measurements of the depths of the interface are made by passing a source of neutrons through the borehole so that neutrons from the source will bombard the surrounding material, measuring the intensity of scattered neutrons in the vicinity of the source and noting changes in the intensity caused by the absorption of the neutrons by said neutron-reactive substance, and correlating the points of said intensity changes with depth in the hole.

4. The method as described in claim 1 in which the measurements of the depths of the interface are made by passing a source of neutrons through the borehole so that neutrons from the source will bombard the surrounding material to induce gamma rays therein, measuring the intensity of the high energy induced gamma rays while discriminating against low energy gamma rays in the vicinity of the source as said intensity is changed by the capture of neutrons by said neutron-reactive substance, and correlating the points of said intensity changes with depth in the hole.

5. The method as described in claim 1 in which the fluids are salt water and the measurements of the depths of the interface are made by passing a source of neutrons through the borehole so that neutrons from the source will bombard the surrounding salt water, measuring in the vicinity of the source the intensity of high energy gamma rays induced in the salt water by said bombardment, noting changes in said intensity caused by the presence or absence of said neutron-reactive substance in said salt water and correlating the points of said intensity changes with depth in the hole.

6. The method of making a permeability profile log of a subsurface formation traversed by a borehole which comprises pumping a liquid into said borehole above said formation, said liquid containing a small amount of a boron compound, simultaneously pumping a similar liquid free from said boron compound into said borehole below said formation, thereby establishing an interface between said liquids, determining the depth in the hole of said interface by measuring the effect of neutron bombardment on said compound in the liquid throughout that portion of the hole opposite said formation, varying the ratio of the pumping rates of the two liquids while maintaining constant the total amount of liquid being pumped so as to cause said interface to move along the walls of said formation to a new depth, determining the new depth of the interface by making another measurement of the effect of neutron bombardment on the liquid in the hole, and repeating these operations while noting the ratios of the two liquids being pumped for each measured depth of the interface in the hole.

7. The method as described in claim 6 in which the measurements of the depths of the interface are made by passing a source of neutrons through the borehole so that neutrons from the source will bombard the surrounding material, measuring the intensity of scattered neutrons in the vicinity of the source as said intensity is changed by the absorption of the neutrons by said boron compound, and correlating the points of said intensity changes with depth in the hole.

8. The method as described in claim 6 in which the measurments of the depths of the interface are made by passing a source of neutrons through the borehole so that neutrons from the source will bombard the surrounding liquids, measuring in the vicinity of the source the intensity of gamma rays having energies of about 0.5 mev. induced in the boron in said boron-containing liquid by said bombardment while discriminating against gamma rays of higher energies, noting changes in said intensity caused by the presence or absence of said boron in said liquid and correlating the points of said intensity changes with depth in the hole.

9. The method described in claim 1 in which acid is to be injected into the oil-containing portion of a gas- and oil-bearing formation and in which one of the pumped fluids is a solution of hydrochloric acid while the other pumped fluid is fresh water, the interface being located as described in claim 1 by virtue of the large neutron capture cross section of the chlorine in the acid as compared to the neutron capture cross section of the fresh water, the rates of injection of the water and acid being adjusted so as to maintain the water-acid interface near the boundary between the gas-containing and oil-containing portions of the formation so that the acid will enter the oil-containing portion.

10. The method described in claim 9 in which the formation comprises an oil-containing portion above and in contact with a water-containing portion and in which the rates of injection of the water and acid are adjusted so as to maintain the interface near the boundary between the oil-containing and water-containing portions of the formation so that the acid will enter the oil-containing portion.

11. The method of determining the relative rates of the flow of fluid through adjacent sections of the wall of a borehole containing a string of tubing extending down at least as far as the bottom of the zone in which measurements are to be made, which comprises controlling the rates of flow of fluid through said tubing and through the annulus between the tubing and the hole walls so that a "null point" will exist in the annulus within said zone between fluid flowing in said tubing and the fluid flowing in said annulus, introducing a neutron reactive substance into the fluid in the annulus measuring the depth in the hole of said null point by determining the response of the fluids to neutron bombardment, varying the ratio of the flow rates of the fluids in the tubing and in the annulus while maintaining constant the sum of the rates of the two fluids so as to cause said null point to move along the wall of the borehole to a new position, determining the depth of the null point at said new position, and repeating these operations while noting the ratios of the flow rates of the two fluids for each measured depth of the null point in the borehole.

12. The method of productivity well logging of a borehole traversing subsurface formations and containing a string of tubing extending down at least as far as the bottom of a zone in which measurements are to be made which comprises regulating the pressure at the well head of said borehole to provide for flow of fluid from said zone of the formation surrounding the well bore into said well bore, controlling the resistance to flow of the fluid both in said tubing and in the annulus between the tubing and the borehole wall so that said flow of fluid from said zone divides into a portion flowing upwardly through said tubing and another portion flowing upwardly through said annulus, measuring the rates of flow of said two fluid streams, also determining the depth of the "null point" existing in said annulus within said zone between fluid flowing downwardly into the lower end of said tubing and the fluid flowing upwardly in said annulus at said rates of flow, altering the relative resistances to the rates of flow of said two streams while maintaining the total rate of production constant, again measuring the rates of flow of the two streams and also determining the depth of the "null point" at its new position resulting from the change in the relative rates of flow of said streams, and repeating these operations while noting the ratios of the flow rates of the two fluids for each measured depth of the "null point" in the hole.

13. The method defined in claim 12 in which the depth of the null point is measured by injecting a tracer into the fluid flowing into the borehole at a known depth while determining whether the tracer flows upwardly with the fluid stream in the tubing or with the fluid stream in the annulus, and changing the height of the point of tracer

injection until the tracer flows upwardly in the other stream, the depth at which the tracer changes from one stream to the other corresponding to the depth of said null point.

14. The method defined in claim 13 in which the tracer is a neutron-reactive material, the location of which is determined by bombarding the fluid streams with neutrons from a source within the borehole while measuring the secondary radiation returning to the vicinity of the source vertically in the borehole and noting the depth

at which a pronounced change in the intensity of said measured secondary radiation takes place.

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