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GROUNDWATER DIRECTION DETERMINATION

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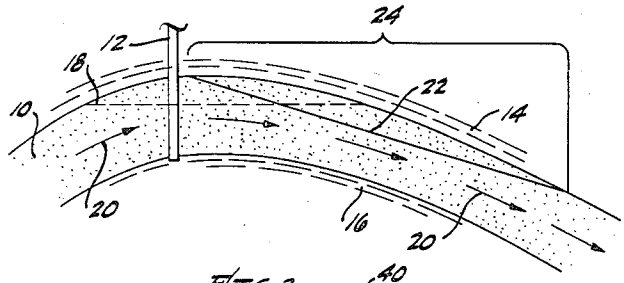


FIG. 1.

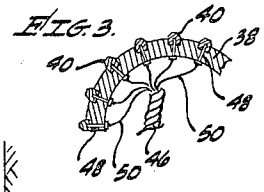


FIG. 3.

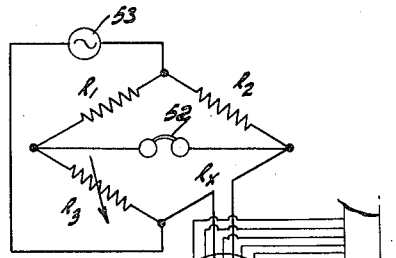


FIG. 4.

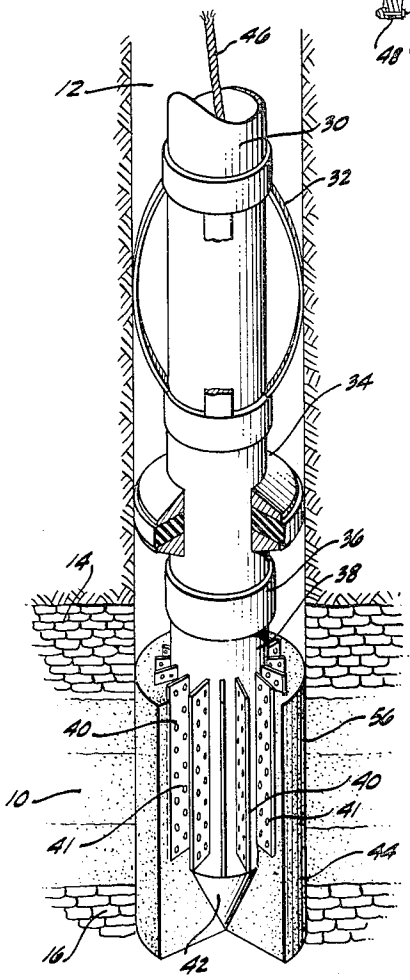


FIG. 2.

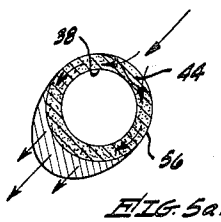


FIG. 5a.

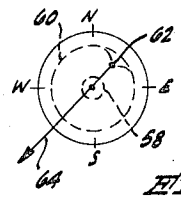


FIG. 5b.

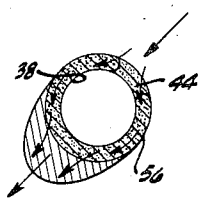


FIG. 6a.

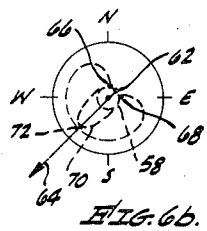


FIG. 6b.

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GROUNDWATER DIRECTION DETERMINATION

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17 Claims. (Cl. 324—1)

This invention relates to underground exploration by means of bores drilled into the earth's crust and particularly relates to an improved method and apparatus for the detection of the direction of flow of groundwater through fluid permeable underground formations in connection with geophysical exploration for crude oil and gas deposits and the like.

Crude petroleum and gas are frequently found trapped in arching geological structures known as anticlines. Fluids are contained in the porous and permeable rock such as sandstone which arches upwardly underneath an overlying layer of impermeable rock. Any gas which may be present usually exists as a cap at the top and a layer of petroleum saturates the permeable formation immediately below the gas cap. Further down in the formation is the groundwater or brine usually present with the gas and the oil. Frequently the anticlinal structures have plural arches connected to each other in a series which generally slope from one end to the other of the series. In other words, the peaks of each of the connected anticlines in a given direction may be successively higher or lower in a given direction with a general change in height that may vary on the order of 100 to 800 feet per mile.

Frequently in such sloped structures the groundwater tends to flow, having a source perhaps in a mountainous region at the high end from which water drains through the anticlinal structure toward a sink of one sort or another at the lower end. The net movement of the groundwater through the permeable rock below the oil and gas layers trapped beneath each anticline exerts hydrodynamic forces on the oil and gas and tends to move it in a direction of the groundwater flow down the structure from the position at which it would otherwise be expected just beneath the arch. Thus wildcat well bores drilled in unproven territories into an anticline crest, which is located by any of the many well-known geophysical exploration methods, frequently will exhibit traces of oil and gas but no sufficient amount to constitute commercial production. There is otherwise no other available criteria to determine the most likely direction to drill the next well into the displaced deposit of oil and gas. The flow velocities are of the order of 0.1 inch per day and the pressure gradient associated with this flow is of the order of 3×10^{-6} pounds per square inch per foot. Obviously these minute velocities and pressure gradients are immeasurable by any of the conventional means under wellbore conditions.

The present invention is therefore directed to a process and apparatus through which these flow directions are determined by disposing in an annular-shaped test zone within the wellbore an electrical conductivity modifier fluid and measuring the variations in conductivity of a plurality of sections around the test zone with time as the indigenous fluid flows through.

It is therefore a primary object of this invention to provide a method and apparatus for the determination of

the direction and approximate flow rate of groundwater which moves through underground permeable strata.

It is an additional object to determine the appropriate location for additional wildcat wellbores on the basis of a determination of the flow direction of groundwater located in permeable strata penetrated by a previous wellbore.

It is a specific object of this invention to improve the efficiency of the discovery of crude petroleum and other valuable materials by means of wildcat wells through the selection of additional well sites after a determination of the direction of groundwater flow in a previously drilled wellbore.

Other objects and advantages of the present invention will become apparent to those skilled in the art as the description and illustration thereof proceed.

Briefly the present invention comprises the determination of the direction of flow of groundwater or other underground indigenous fluids through subterranean permeable strata by providing a conductivity modifier ingredient, to produce in the test zone an electrical conductivity or resistivity substantially different from that of the groundwater or other fluid whose flow is to be detected, in an annular-shaped test zone in the bore in the region where it penetrates the permeable strata and detecting the migration of this added fluid through variations in electrical conductivity. This injected modifier ingredient is contained in the bore in a sand pack or in any similar solid body which is permeable to fluid flow in a portion of the bore opposite the permeable strata through which the groundwater flows. Approximately at the center of this mass of fluid permeable material is placed a lance or other means on which is disposed a plurality of electrodes. This leaves an annular-shaped fluid-permeable solid body, containing the fluid having the distinctive conductivity or resistivity, existing between the outer surface of the lance and the borehole walls in the annular test zone. The normal flow of groundwater transversely through the permeable strata tends to displace the added fluid in the sand pack, and progressive changes in the electrical conductivity in the test zone occur.

Immediately after placement of the sand pack and the modifier fluid, conductivity or resistivity measurements are made in the conventional way between each pair of electrodes around through the test zone and these values are recorded. As the intrusion of the groundwater progresses, the detected conductivity changes due to dilution, displacement, and migration effects which cause the modifier fluid to flow laterally through the annular-shaped sand pack and off into the permeable formation in the opposite direction. These changes are first noticed with respect to electrodes disposed on the upstream side of the lance facing the apparent source of groundwater flow. Gradually, further changes are detected between electrodes located around the lance moving in the downstream direction. The change in resistivity is followed in terms of the instantaneous value of conductivity relative to the original value on polar coordinates as a function of the azimuthal location of each pair of electrodes. The indigenous fluid flow direction is along a line drawn from the point of first conductivity change through the wellbore axis and on through the point of last conductivity change. Thus, and as hereinafter more fully illustrated, the flow direction of the indigenous fluid is readily determined by the first as well as by subsequent changes in detected and recorded conductivity.

Once the flow direction of the groundwater has thus been determined from the indications of conductivity change, the most likely direction of shift of trapped oil and gas deposits from the top of an anticline may be determined and subsequent wells may be drilled into

the anticline along a line extending in the same direction as the groundwater flow from the first well in which the groundwater flow direction was determined.

The method and apparatus of the present invention will be more readily understood by reference to the accompanying drawings in which:

Figure 1 is a vertical cross section view in schematic form of an arching geological structure known as an anticline and in which the groundwater flow has shifted an oil and gas deposit,

Figure 2 is an isometric detail view of the apparatus of this invention located at the intersection of a wellbore and an underground permeable stratum,

Figure 3 is a transverse detailed cross section view of a portion of the lance carrying the electrodes by means of which changes in conductivity and resistivity may be detected,

Figure 4 is an electrical diagram of a suitable bridge circuit and switching arrangement for determining conductivity or resistivity changes between the various electrodes during groundwater intrusion,

Figures 5A and 5B indicate schematically the initial displacement of the special fluid by the groundwater flow and the relative conductivity determined according to the method of this invention, and

Figures 6A and 6B indicate the same information as Figures 5A and 5B but at a later time and after further groundwater intrusion.

Referring now more particularly to Figure 1, an arching structure **10** of permeable rock is penetrated by well bore **12**. This arching structure is known as an anticline and is overlain by one or more layers of fluid-impermeable rock **14** and underlain by other nonfluid-containing layers **16**. The specific gravity of petroleum gas and oil is nearly always less than that of the brine which constitutes the groundwater frequently associated with it. Accordingly these hydrocarbon materials migrate upwardly and tend to collect in anticlinal traps such as that shown in this figure. Because of the fluid-impermeable stratum **14** the accumulation of petroleum ordinarily exists above broken line **18**. In the absence of groundwater flow this line **18** constituting the lower extremity of the petroleum deposit will be substantially level or horizontal. When however the groundwater flows in the direction indicated by arrows **20**, the hydrodynamic effect of such flow is to displace the petroleum deposit to the right in permeable stratum **10** so that it occupies the position indicated between line **22** and the lower surface of impermeable stratum **14**.

There are many geophysical methods for locating the approximate position of an anticlinal structure. Once the approximate location is determined the site for drilling wellbore **12** is readily picked. If the petroleum deposit were undisplaced, then wellbore **12** would be expected to produce commercial quantities of petroleum. However, with the deposit displaced into a position embraced in bracket **24**, wellbore **12** drilled at approximately the crest of the anticline will show little more than traces of oil and gas. The present invention is directed to the use of wellbore **12** to determine the direction of groundwater flow and the most likely direction of displacement of the gas and oil so that a logical direction for drilling further wells may be picked with the first well as a reference point.

Referring now more particularly to Figure 2, borehole **12** is shown extending downwardly through superjacent impermeable strata **14**, permeable strata **10**, and subjacent impermeable strata **16** as indicated previously in Figure 1. Well tubing **30** extends downwardly through the borehole **12** and is provided with tubing centralizer **32** and packer **34**. Packer **34** is provided immediately above lance **38** and serves to isolate the test zone from the rest of the borehole. By means of collar **36** electrode lance **38**, provided with a plurality of peripheral electrodes **40**, is connected at the lower extremity of tubing string **30**. Lance **38** is provided at its lower end with a conical point **42** by means of which the lance and its peripheral electrodes may be forced downwardly into sand pack **44**. Electrodes **40** are provided throughout their entire length with lateral perforations **41** to permit flow therethrough of the indigenous fluids.

Sand pack **44** is placed in the borehole opposite permeable stratum **10** by any of the conventionally practiced sand pack placement methods. The pack may be placed in the borehole either before or after placement of the lance therein. Either before placement of the sand pack or after placement thereof, an ingredient is incorporated in the granular solids to impart a significantly different conductivity or resistivity to fluids either present originally therein or added with the ingredient or formed after intrusion of the initial groundwater flow. The conductivity or resistivity should be significantly different, either higher or lower, from that of the usual groundwater or brine. This may be accomplished using higher conductivities by dispersing in a dry or substantially dry sand pack finely divided particles of water soluble ionizable solid salts such as sodium chloride for example, or moistening of the sand pack before placement with a solution of water soluble solids such as sodium chloride, or any other means. Conductivity water may be employed instead, whereby the conductivity measured in the test rises from a very low value to the normal value. An alcohol-miscible with water may also be used to effect a large variation on the conductivity. Preferably the ingredient added is either soluble in or miscible with the indigenous fluid to be detected and does not cause precipitation or other phase changes. Any material which changes the conductivity from that of the indigenous fluid may be used.

After disposition of the lance and the electrodes and the sand pack surrounding the electrodes within the wellbore, a plurality of initial conductivity or resistivity measurements are made between selected pairs of electrodes around the lance periphery. This serves to indicate the original conductivity of the matrix which fills the space between the adjacent electrodes and to which subsequent changes may be related or compared. This determination is preferably conducted remotely at the surface of the earth, by means of an instrument subsequently described, and to which each of the electrodes are connected by means of a plural conductor cable **46** which extends upwardly to the surface through tubing string **30**.

Referring now more particularly to Figure 3, an enlarged detailed drawing of a portion of a transverse cross section of lance **38** is shown. The lance preferably is constructed in tubular form of mechanically strong electrically insulating material such as laminated glass fiber and resin materials or the like and in which a plurality of longitudinal parallel spaced slots are milled or otherwise cut on the exterior surface. Into each of these slots is secured an elongated electrode **40** by means of fasteners **48**. These fasteners also constitute the electrical connection between the electrode and one of the individual conductors **50** contained within cable **46**. By means of these conductors and this cable the individual electrodes communicate with a conductivity or resistivity detecting device located at the surface. For this purpose, an alternating current Wheatstone bridge is suitable.

Referring now more particularly to Figure 4, a schematic diagram of an alternating current Wheatstone bridge is shown. This consists of a bridge circuit including serially connected resistances R_1 and R_2 which are preferably equal in electrical resistance, and a variable resistance R_3 and the unknown resistor R_x, which latter is the unknown resistance between any adjacent pair of electrodes. Element **52** indicates a visual or audio or other type of null indicator while element **53** indicates an electrical generator capable of producing an

alternating current voltage, usually of a frequency within the audio range, namely between about 30 and about 10,000 cycles per second. Alternating current is employed to avoid gas deposition and ion depletion polarization effects at the electrode surfaces. With R_1 electrically equal in resistance to R_2 and an alternating current voltage applied at the points indicated by generator **53**, a zero voltage or null will be indicated by indicator **52** when R_3 is adjusted to be equal in resistance to the resistance R_x between any pair of electrodes. From this measured resistance and knowing the length and spacing and transverse area of the individual electrodes **40**, the conductivity or resistivity of the medium therebetween may be determined. In the Wheatstone bridge circuit, rotary switch **54** is provided by means of which any pair of conductors **50** may be selected for connection into the bridge circuit. The pairs of conductors so selected are those which are connected to adjacent pairs of electrodes in lance **38** as indicated in Figures 2 and 3.

Referring now to Figure 5A, a transverse view of the annular test zone **44** contained between the borehole wall **56** and the outside surface of lance **38** is shown. The wide-spaced cross hatching indicates the sand pack. The area denoted by the close-spaced cross hatching indicates the volume of fluid containing the added ingredient which causes the marked deviation in conductivity of the fluid from that of the normal groundwater. For purposes of example, the conductivity modifier is sodium chloride forming a more highly conductive brine than the indigenous groundwater. As indicated at the upper right-hand portion of sand pack **44**, an intrusion of groundwater from a northeasterly direction has displaced the fluid of abnormal conductivity around through the annular sand pack and off to the southwest into the adjacent permeable strata. The relative conductivity of the fluid existing at the point of groundwater intrusion thus approaches the normal conductivity for the groundwater and thus indicates the point of intrusion and the direction of groundwater flow.

Referring now to Figure 5B the relative conductivity data taken as described previously is plotted on polar coordinates. The inner circle **58** represents the normal groundwater conductivity whereas the outer circle **60** indicates the initial high relative conductivity of the sodium chloride treated sand pack immediately after placement. Because of the northeasterly intrusion of groundwater, the first tendency toward return to normal groundwater conductivity is noted at point **62** between the electrodes facing the apparent groundwater source toward the northeast. Line **64** drawn through point **62**, the first conductivity change, and the center of the graph indicates a groundwater flow in a southwesterly direction.

Referring finally to Figures 6A and 6B, which correspond respectively to Figures 5A and 5B, a later condition is depicted following further intrusion of groundwater flow. It is noted that the intrusion of groundwater has caused the original fluid of special conductivity to be displaced a substantial distance around through the annular sand pack. In Figure 6B it is noted that the substantial return to normal groundwater conductivity has occurred over a substantial proportion of the sand pack periphery, namely between points **66** and **68**. These data tend to confirm further the southwesterly flow of groundwater in the particular instance here depicted. If allowed to continue, a curve such as is indicated at **70** would ultimately be obtained giving a confirming point **72** on flow direction arrow **64**. This would be the last change in conductivity. Thus the direction of flow of groundwater by means of changes in relative conductivity or resistivity of a sand pack placed in the borehole may be obtained.

From the data determined according to the method of the present invention and applying known geometric and hydrodynamic relations, the change of the detected variable with time also serves to give an indication of the flow rate of the groundwater through the region of the intersection of the permeable strata and the borehole. With groundwater flows which are relatively rapid, the return of the sand pack condition to the norm corresponding to the presence of groundwater in the sand pack is relatively rapid. In the opposite case when this flow is relatively slow the change in sand pack condition, with respect to the measured variable, is relatively slow. Knowing the required time for this variation, one may readily estimate the flow velocities.

It is apparent from the practice of the present invention as described above that the location of nearby deposits of gas and oil and other valuable fluids found in underground permeable strata, has been improved. It is contemplated in the practice of this invention that the usual geophysical methods will be applied in locating the anticlinal type of structure or other characteristic types of structures in which such valuable fluids are found. It is further contemplated that at least one wildcat wellbore will be drilled into this structure so as to expose the permeable strata and render the path of groundwater flow accessible for analysis. The present invention is intended to be used in this analysis, specifically to determine the direction of groundwater flow past the wellbore in those cases where traces of valuable fluids have been found in the bore in order to indicate the most likely direction which the main body of these valuable fluids have been displaced by the groundwater flow.

A particular embodiment of the present invention has been hereinabove described in considerable detail by way of illustration. It should be understood that various other modifications and adaptations thereof may be made by those skilled in this particular art without departing from the spirit and scope of this invention as set forth in the appended claims.

We claim:

1. A method for determining the direction of fluids flowing slowly through underground permeable strata penetrated by a wellbore which comprises forming an annular-shaped fluid-permeable test zone within said borehole opposite said strata, incorporating within said test zone an electrical conductivity modifier ingredient so as to provide therein a fluid having an electrical conductivity substantially different from that of the indigenous fluids flowing in said strata, packing off said test zone from the remainder of said borehole, and measuring the variation in electrical conductivity of a plurality of incremental sections around said test zone with time caused by transverse flow of indigenous fluids therethrough.

2. A method according to claim 1 in combination with the step of preliminarily measuring the conductivity of each of said sections before any substantial flow of said indigenous fluid occurs.

3. A method according to claim 1 wherein said electrical conductivity modifier provides an initial conductivity substantially greater than that of the indigenous fluids.

4. A method according to claim 1 wherein said electrical conductivity modifier provides an initial conductivity substantially below that of the indigenous fluids.

5. A method according to claim 1 wherein said annular-shaped test zone is formed by the steps of placing within said borehole a body of granular solids, said body being permeable to fluid flow, and thereafter displacing said body into annular shape by forcing downwardly into the center thereof an elongated lance.

6. A method according to claim 1 wherein said annular-shaped test zone is formed by the steps of first placing an elongated lance substantially along the borehole axis in said test zone, and thereafter filling the annular space in said test zone with a body of granular solid material.

7. In a method for discovering and producing petroleum hydrocarbons from underground permeable strata which comprises drilling a wellbore from the surface

into said permeable strata and locating at most noncommercial quantities of such hydrocarbons, the improved method for selecting the site for subsequent wellbores by determining the flow direction of fluids indigenous to said strata which comprises forming an annular-shaped fluid-permeable test zone within said wellbore opposite said permeable strata, disposing an electrical conductivity modifier in said test zone, packing off said test zone from the remainder of said wellbore to force the indigenous fluid to flow transversely through said test zone and displace said modifier therefrom, measuring the variation with time in the electrical conductivity between a plurality of adjacent points around said test zone, whereby the flow direction of fluids through said test zone lies along a line drawn through the point of first conductivity change and the axis of said wellbore, and drilling an additional wellbore into the strata substantially from a point on the surface located along a line drawn in the determined flow direction through the location on the surface of the first wellbore.

8. A method according to claim 7 wherein said conductivity modifier comprises conductivity water having a substantially lower conductivity than indigenous brine in said strata.

9. A method according to claim 7 wherein said conductivity modifier comprises an ionizable water soluble salt which imparts to said indigenous fluids a substantially higher electrical conductivity.

10. A method according to claim 7 in combination with the step of preliminarily measuring the conductivity between each pair of a plurality of points disposed around said test zone before any substantial flow of indigenous fluid therethrough, the detected conductivities constituting reference values to which subsequent conductivities between corresponding points are referred.

11. A method according to claim 7 wherein the indigenous fluid flow is allowed to continue through said test zone until the initial conductivity is restored between the last pair of points, the flow direction lying along a line drawn from the point at which normal conductivity was first restored, through the wellbore axis, and on through the point at which normal conductivity was last restored.

12. An apparatus for determining the flow direction of fluids moving in underground fluid-permeable strata penetrated by a wellbore which comprises a packer isolating one portion of said wellbore from the remainder thereof, a substantially annular-shaped body of fluid-permeable solid material disposed in the isolated portion of said bore, an electrical conductivity modifier ingredient distributed within said annular-shaped body, a plurality of electrodes spaced apart from one another around said annular-shaped body, conductivity measuring means disposed at the surface of the earth, and a plural conductor cable extending through said wellbore connecting said electrodes to said last-named means.

13. An apparatus according to claim 12 wherein said conductivity measuring means comprises an alternating current bridge circuit, and switching means for connecting said bridge circuit via said cable to any pair of said electrodes.

14. An apparatus according to claim 12 in combination with an elongated lance centrally disposed within said annular-shaped body, said electrodes comprising elongated metallic strips disposed parallel to one another longitudinally around the outer surface of said lance.

15. An apparatus according to claim 14 wherein said lance is connected to the lower end of a tubing string extending through said wellbore.

16. An apparatus according to claim 14 wherein said lance is provided with a pointed lower end whereby it is adapted to be projected downwardly into a body of granular solid material in said wellbore to displace said body into an annular-shaped body of solids.

17. An apparatus according to claim 14 wherein the plurality of electrodes each comprises an elongated metallic element of substantial radial width disposed longitudinally and radially around the outer periphery of said lance, said elements being perforated along substantially their entire length to permit fluid flow therethrough.

References Cited in the file of this patent

UNITED STATES PATENTS

2,539,355 Reichertz ---------- Jan. 23, 1951