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METHOD OF DETERMINING THE PERMEABILITY OF EARTH FORMATIONS

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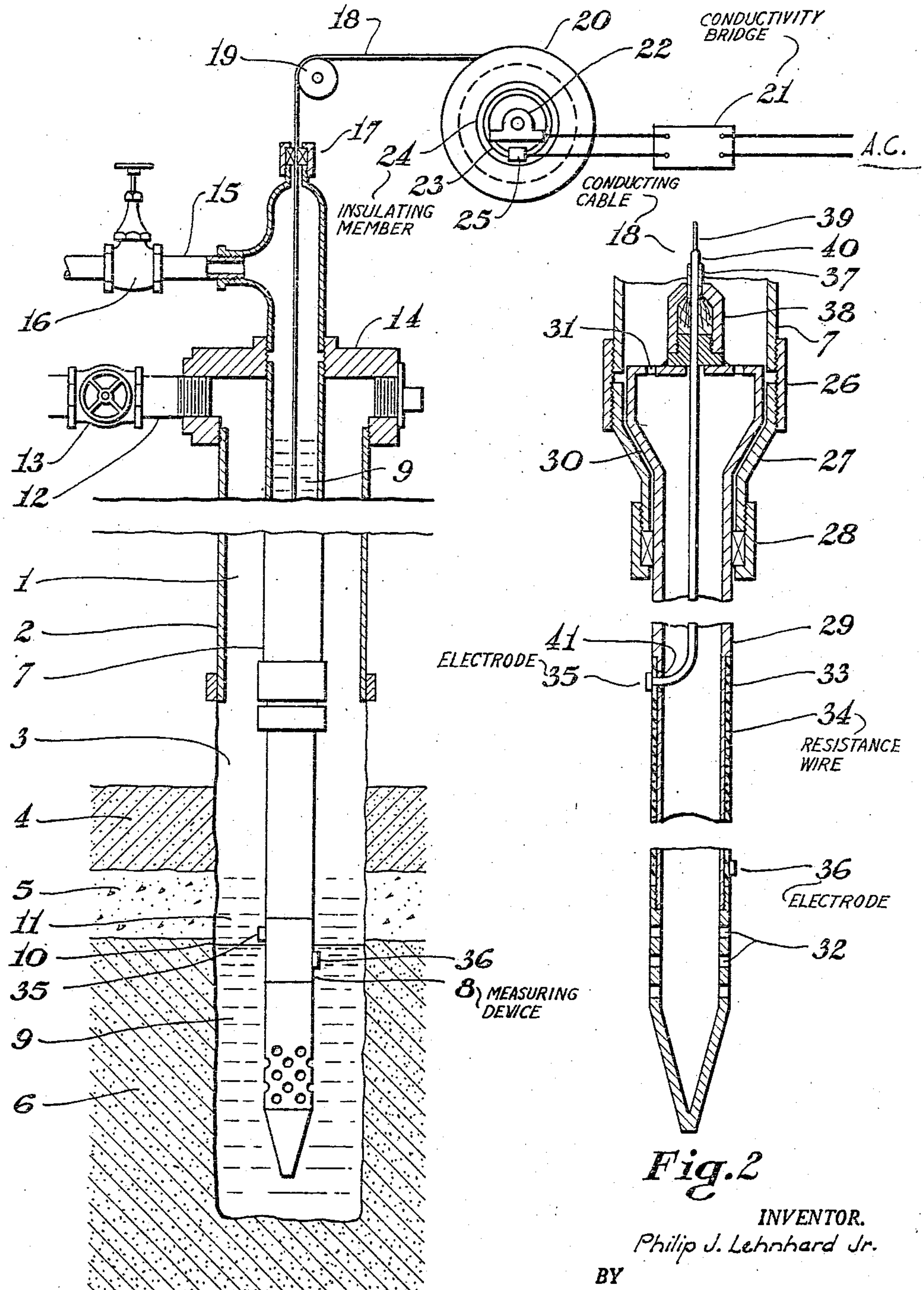

Fig. 1

Fig. 2

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METHOD OF DETERMINING THE PERMEABILITY OF EARTH FORMATIONS

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2 Claims. (Cl. 73—152)

The invention relates to a method of determining the permeability of formations or portions thereof penetrated by the bore of a well. It is more particularly concerned with a method wherein rates of flow of fluids from the well bore into known portions of the formations surrounding the well bore are employed to indicate the permeability of the surrounding formations.

In introducing liquid agents into an earth or rock formation such as, for example, when introducing acid solutions into a porous, calcareous productive formation penetrated by the bore of an oil well, it is desirable to know which portion of the formation is more permeable so that the fluid treating agent may be controlled, permitting its injection into the least permeable sections in order that a more desirable result may be obtained as regards the increased production. In many instances such as, for example, cementing operations, well completions, and formation testing, it is similarly desirable to obtain knowledge readily relative to the permeability of the various strata or sections thereof penetrated by the bore of a well.

It is, therefore, the principal object of the invention to provide a method whereby the permeability to fluids of several strata, or selected sections of one stratum, may be readily determined.

Another object of the invention is to provide a method whereby the relative permeability of the various permeable sections adjacent the well bore can be readily ascertained so as to provide a complete permeability profile of the various permeable sections penetrated by the well bore.

Other further objects and advantages of the invention will be apparent during the course of the following description.

The invention, then, consists in the method hereinafter more fully described and particularly pointed out in the claims, the accompanying drawing, and the following description setting forth in detail a mode of carrying out the invention, such mode illustrating, however, but one of the various ways of putting the invention into effect.

Figure 1 is a digrammatic view partly in section of an oil well equipped for carrying out a permeability determination according to the method of the invention.

Figure 2 is a detailed view in cross section of the lower portion of the apparatus adapted to be used in connection with the permeability determination.

As shown in Figure 1 the upper portion 1 of the well bore is cased with metal pipe 2 while the lower portion 3 of the well bore penetrates a permeable stratum 4, an impermeable stratum 5, and a permeable stratum 6. The well tubing string 7 acts to carry or support a measuring device 8 adapted to indicate the level of a conducting fluid in the well bore. This device is shown located adjacent the productive stratum 6 so that the level of the fluid may be ascertained and held at a point near the top of stratum 6. The lower portion 3 of the well bore, together with the well tubing, is shown filled with an electrolyte solution 9, such as brine, up to a point 10 adjacent the upper level of the permeable stratum 6. The remainder of the well bore consisting of the annular space between the tubing and the casing is shown filled with a nonconductive fluid 11 such as oil. Above the ground level pipe 12 controlled by valve 13 communicates with the interior of the well through the casing head 14, while pipe 15, controlled by valve 16, communicates with the well bore through the tubing string 7. Extending through the packing gland 17 attached to the upper end of the tubing string 7 an electrical conducting cable 18 passes over sheave 19 to carrying reel 20. The conducting cable 18 contains two separate conductors and serves to carry current to and from the measuring device carried by the lower end of the tubing and also serves as a means whereby the measuring device may be raised and lowered through the tubing string. An electric circuit is employed in connection with the measuring device 8 for the purpose of indicating the level of the electrolyte and may, as shown, consist of a source of alternating current, such as a 25 or 60 cycle 110 volt alternating current source, the terminals of which are connected to a Leeds and Northrup or other suitable alternating current conductivity bridge 21. One lead from the conductivity bridge is electrically connected to the reel shaft and reel shaft support 22 which in turn is electrically connected with one conductor of conducting cable 18. The other lead from the conductivity bridge is connected to a ring 23 insulated from reel 20 by insulation 24. The ring 23 is connected to the other lead of conducting cable 18. A brush 25 is provided to maintain electrical contact between the bridge lead and the ring 23 as the reel is rotated.

In the more detailed view of the measuring device shown in Figure 2 a conventional iron collar or coupling 26 is threaded to the lower end of the tubing string 7 and a tapered seat member 27. Attached to the seat member 27 in screw threaded engagement therewith is a packing gland 28 through which the tubular body member 29 can be slidably moved in sealing relationship. The tubular body member 29 of the measuring device formed of metal or other electrically conducting material is shown enlarged at the upper end to form a tapered seating portion 30 which conforms to the inner surface of the seat member 27, thus producing a seal when the surfaces are maintained in contacting relationship. Entry ports 31 and exit ports 32 are provided at the upper and lower ends, respectively, of the tubular member 29 and serve as a means whereby liquid can pass through the measuring device 8 into the well bore from the well tubing 7. The section of the tubular member 29 carries an electrically insulating shell 33 made of "Bakelite," hard rubber, or the like. Completely embedded in the insulating shell is a resistance wire 34 which is wound spirally about the insulating shell 33. The resistance wire is connected at its upper end to an electrode 35 and at its lower end to an electrode 36 mounted on the insulating shell. The outer conductor 37 of the conducting cable 18 may consist of woven wire and is connected to the upper end of tubular element 29 as by clamping means 38 and may be further secured thereto as by soldering, brazing, or the like. The inner conductor 39 of conducting cable 18 is insulated from the outer conductor 37 by insulation 40. The inner conductor 39 passes through the tubular element 29 and is connected to the upper electrode 35 mounted on shell 33 through insulating bushing 41, while the electrode is also connected to the upper end of resistance wire 34.

In carrying out the method of the invention wherein it is desired to ascertain the relative permeability of stratum 6, for example, the measuring device is positioned so that the electrodes occur adjacent the upper level of the stratum 6. Thereafter an electrolyte solution is introduced into the well through pipe 15 while valve 16 is maintained in an open position and at the same time a nonelectrolyte is introduced into the casing through pipe 12 while valve 13 is maintained open. When the electrolyte reaches the bottom of the well and rises in the well bore to a point adjacent the top of the stratum 6, the lower electrode on the measuring device will be contacted and the electric circuit will be completed through the conducting cable 18 and tubular element 29, which will be indicated on the conductivity bridge 21. Thereafter pressure is applied so as to force electrolyte into the formation and the pumping rates of the electrolyte into the tubing and the nonelectrolyte into the casing are controlled so that the level of the electrolyte is maintained at the desired point between the two electrodes in the well bore. If at any time the electrolyte reaches the upper electrode a marked increase in current flow will be noted and indicated by the unbalancing of the galvanometer in the conductivity bridge. Thus, it will be readily possible to keep the level of the electrolyte at a point between the two electrodes or closely adjacent the upper level of stratum 6. From a knowledge of the pressures being applied and the rate at which the electrolyte solution is entering stratum 6 it will be possible to ascertain the relative permeability of stratum 6. It is preferable to maintain the rate of flow of fluid and the pressure being applied at a nearly constant or fixed figure during the determination of the permeability of a specific section so that the permeability figure will be more readily ascertainable. If it is then further desired to determine the permeability of upper stratum 4, the measuring device will be relocated so that the electrodes become positioned adjacent the upper level of stratum 4, the rate of introduction of the electrolyte being increased so as to allow its level to reach the upper level of stratum 4. Thereafter the introduction of fluids through the tubing and casing will be controlled so as to maintain the level adjacent the upper level of stratum 4, whereby the volume of fluid entering each strata will be known. From a knowledge of the amount entering the lower stratum at a given pressure, it will be readily appreciated that the additional amount of fluid being pumped at a known pressure has entered stratum 4. From a knowledge of the pressure being applied and the volumes of fluid being injected into each stratum it will be possible to accurately calculate the relative permeability of the upper stratum.

In a similar manner, if it is desired to ascertain the permeability of a specific section of a single productive stratum, it will only be necessary to first ascertain the permeability of the formation up to the lower level of the specific section and thereafter control the level of the fluid about the upper level of the stratum while applying sufficient pressure to force fluid into the formation. Additionally, it will be understood that in the same manner the permeability of all sections of a formation of considerable extent may be readily determined. In the foregoing manner it is possible to readily obtain a complete permeability profile of the entire open bore hole.

While it is generally preferred to carry out the method employing the apparatus described herein it is to be understood that other types of apparatus may be employed for carrying out the method.

I claim:

1. In a method of determining the permeability of a formation penetrated by the bore of a well, the steps which comprise introducing two immiscible fluids into the well bore, one being of higher specific gravity and electrical conductivity than the other, so as to form two layers of fluid in the well bore, ascertaining the position of one of the fluids in the well bore, maintaining one of said fluids adjacent the portion of the formation the permeability of which is to be tested, by controlling the rate of introduction of said fluids into the well bore and forcing the fluid adjacent the section of the formation to be tested into that portion of the formation at a known rate and under a known pressure, whereby said known rate gives an indication of the permeability of that portion of the formation.

2. In a method of determining the permeability of at least a portion of the formation penetrated by the bore of a well, the steps which comprise introducing oil and brine into the well bore while maintaining said fluids out of contact with each other until they reach the lower portion of the well bore, electrically ascertaining the liquid interface in the well bore, controlling said interface at a point adjacent the upper level of the formation to be tested, applying pressure so as to force the brine into said formation at a known rate under the known pressure, whereby said known rate gives an indication of the permeability of that section of the formation.

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