

July 4, 1944.

G. L. HASSLER

2,352,834

METHOD OF AND MEANS FOR ADJUSTING FLOW RATES OF FLUIDS
THROUGH FORMATIONS TRAVERSED BY BOREHOLES

Filed May 9, 1942

2 Sheets-Sheet 1

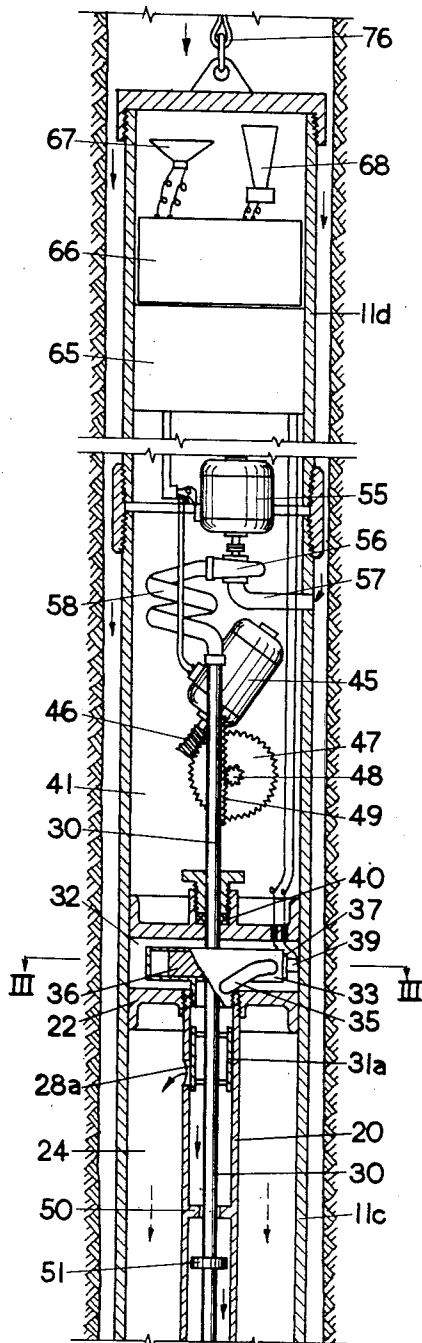


Fig. I

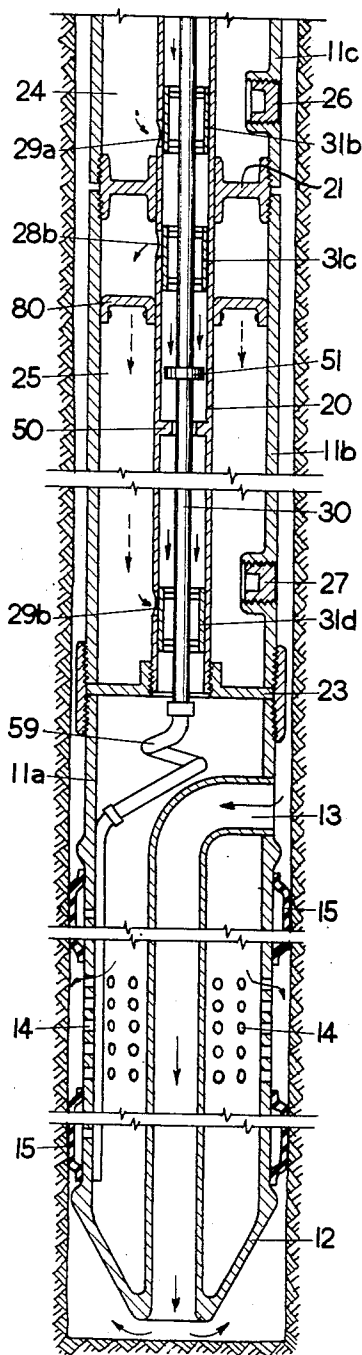


Fig. II

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2 Sheets-Sheet 2

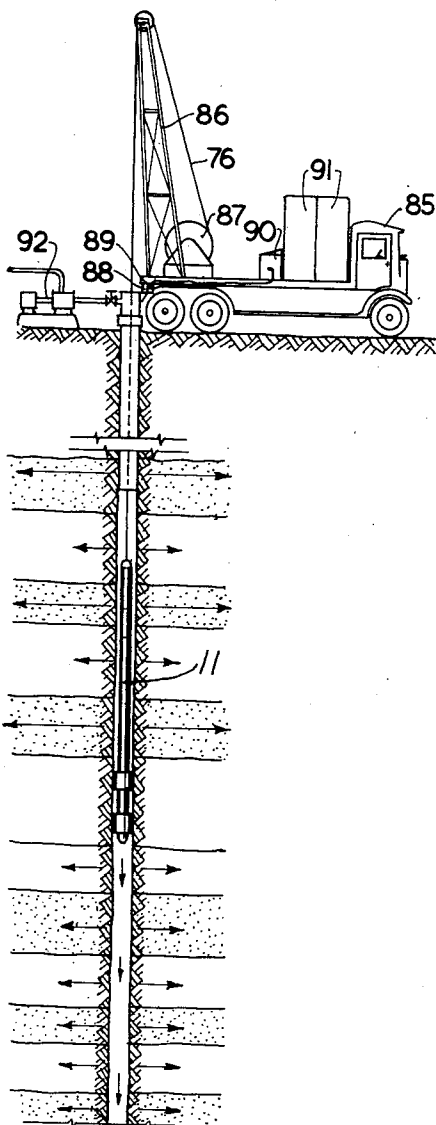


Fig. IV

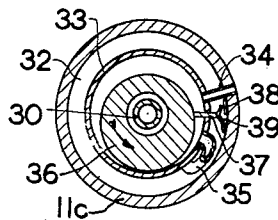
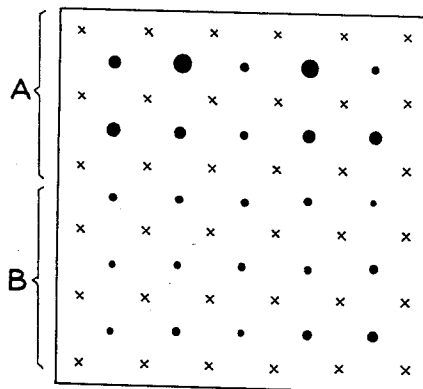


Fig. III



- x Producing Well
- Injection well taking too much water
- Injection well taking balanced share of water

Fig. V

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UNITED STATES PATENT OFFICE

2,352,834

METHOD OF AND MEANS FOR ADJUSTING
FLOW RATES OF FLUIDS THROUGH FOR-
MATIONS TRAVERSED BY BOREHOLESGerald L. Hassler, Berkeley, Calif., assignor to
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7 Claims. (Cl. 166—1)

The present invention relates to methods of drilling and producing oil and gas wells and pertains more particularly to methods of determining the properties of formations traversed by a borehole.

Generally, in oil wells, the strata traversed by the borehole vary considerably in their ability to conduct fluid therethrough. This difference in permeability of the various strata gives rise to considerable difficulties, particularly in repressuring or flooding systems for secondary recovery of depleted oil sands wherein a complete or uniform recovery from the various oil-bearing strata cannot be obtained, since a high rate of recovery of oil is effected from the highly permeable strata while a low recovery is attained in the less permeable regions. This condition occurs when repressuring is indiscriminate, as when the flooding fluid, such as air, gas, or water, is forced into a formation from a pressure well without regulation of the pressure, volume, and velocity as between strata of different permeabilities.

To overcome these difficulties, heretofore it has been proposed to place in the injection well of such systems a tubular sleeve with spaced rings of openings of various sizes and with means to seal off the space outside the sleeve between the rings of openings, whereby the flow of fluid into the various strata is controlled by the size of opening communicating with the strata opposite said opening. However, this device is unsatisfactory in that permeability measurements must first be made, then a special sleeve constructed to correspond to said measurements and flow rate calculations, and subsequently the sleeve must be properly placed with relation to depth and permeability. It may be seen that particularly where narrow strata are encountered, these operations, including the measurement of the permeabilities, necessarily must be carried out with extreme accuracy of depth correlation.

It is therefore an object of this invention to provide a device for accurately determining the effective permeability of a porous stratum traversed by a borehole by measuring the rate of liquid flow rate into the stratum.

It is another object to provide a method of transmitting to the surface the data obtained by a permeability-measuring device without the use of expensive and cumbersome electrical cables.

It is also an object of this invention to provide means to measure the effective permeabilities of strata traversed by a borehole and to regulate the amount of flooding fluid taken by the strata to the desired values without the necessity of ex-

tremely accurate correlation of permeability measurements with depth and location of liner sleeves or the like.

It is a further object of this invention to provide surface control means, whereby signals can be transmitted through the mud fluid, drill pipe, or walls of the borehole, for actuating permeability-measuring instrument in a well borehole.

It is still another object of this invention to provide a device for adjusting the effective permeabilities or flow resistances of the desired porous formations in an injection well of a water-flooding system toward a more nearly uniform medium value, whereby flooding water will pass into the various formations at substantially the same rate.

It is also an object of this invention to provide a method and apparatus for isolating a stratum traversed by a well from the rest of the borehole, flowing a liquid into said stratum, measuring the liquid flow rate at a point close to the point of injection into the stratum, and transmitting the measurement to the well surface by means of vibration signals.

It is a still further object of the present invention to provide means for measuring the rate of flow of a liquid into a stratum traversed by a well borehole, and, depending on the measured rate of liquid flow, either decreasing its effective permeability by partially plugging said stratum with finely divided inert material, or increasing its effective permeability by means of acid in order to obtain a predetermined rate of liquid flow into said stratum.

Other objects will be readily apparent from the following description, taken in reference to the drawings, wherein:

Figure I is a longitudinal sectional view of the upper portion of a preferred embodiment of a device used to carry out the present invention, showing said device in operative position in a borehole.

Figure II is a continuation of Figure I, showing the lower portion of said device.

Figure III is a cross-sectional view taken along the line III—III of Figure I.

Figure IV is a schematic vertical sectional view of an oil well with the present device positioned therein.

Figure V is a diagrammatic view of a water flood lease map showing a section of the oil field before treatment and a section after treatment according to the present invention.

Generally, the present invention resides in isolating or packing off a stratum traversed by a

well from the rest of the borehole, for example, by means of expansible packers, passing fluid through said stratum, and measuring the rate of fluid flow through said stratum by means of a flow meter positioned close to the stratum. For the purpose of measuring the effective permeability of a stratum, fluid may be injected thereinto, such as in a repressuring or flooding system, or the naturally-occurring fluids may be allowed to flow from the formation into the packed-off space in the borehole, wherein its rate of efflux may be measured.

Since the present invention is particularly applicable to the regulation of the flow of flooding or repressuring fluid through the various strata of an injection well of a flooding or repressuring system, it will be described in relation thereto. After the effective permeability or flow resistance of a stratum in an injection well has been measured, the walls of the borehole in that stratum are suitably treated to adjust the fluid flow rate to the desired value by flowing into the stratum together with the fluid either a permeability decreasing or plugging material, such as a finely divided, preferably acid-soluble, solid, e. g. chalk, oyster shells, etc., or a permeability increasing material such as an acid capable of forming water-soluble salts with the earth formation, for example, hydrochloric or hydrobromic acids, solvents, for example pyridine or nitrogen bases, etc.

The permeability measurements are preferably indicated at the surface and the control of the expansion of the packers and injection of the plugging material or acid are effected by means of signals or vibrations, such as sound waves or the like, transmitted through the drill stem, the borehole walls or fluid filling the well, or other wave transmission paths available in the well. However, if desired, insulated electric cables may be used in whole or in part to effect such measurement of control communications.

Referring to Figures I, II and III of the drawings, a preferred embodiment of a device for carrying out these operations is contained in a tubular housing 11 (Figure IV) which may be formed of coupled sections 11a, 11b, 11c, and 11d. The lower section 11a, as shown in Figure II, is preferably formed with a tapered lower end 12 and is provided with a fluid by-pass channel 13 there-through. The center or intermediate portion of the lower housing section 11a is perforated as at 14. On either side of this perforated portion the housing member 11a carries expansible sealing means, such as hydraulically-expansible packers 15, which may be formed as inflatable rubber sleeves surrounding said housing member. These rubber sleeves may be quite thin in order to effect a good seal against the rough walls of the borehole.

The central portion of the housing 11 is formed of two tubular housing sections 11b and 11c, and extending therethrough is a tubular member or pipe 20. End plates 22 and 23 and intermediate plate 21, which also acts as a coupling for the housing sections 11b and 11c, surround the pipe 20 and divide the annular space thereabout into two tanks 24 and 25, which may be filled with chalk suspension and acid, respectively, by means of filler plugs 26 and 27. The tanks 24 and 25 are respectively provided with ports 28a and 28b in their upper portion and ports 29a and 29b in their lower portion, which ports communicate with the central channel through pipe 20. A tubular element 30 is reciprocable coaxially in the central pipe 20 and carries valve members 31a,

31b, 31c and 31d which normally close the ports 28a, 28b and 29a and 29b in tanks 24 and 25. Stops 50 within the pipe 20 and ribs 51 on the tubular element 30 limit the reciprocation of said element 30. A flexible conduit 59 attached to the lower end of the tubular element 30 communicates with the interior of the inflatable packers 15.

Preferably directly above the upper end plate 22 of the tank 24 is a chamber 32 which contains a suitable flowmeter 33, shown also in Figure III. A conduit 34 supplies fluid to the flowmeter 33 from the outside of the housing 11c and a second conduit 35 communicates with the central pipe 20 for discharging thereinto fluid from the flowmeter 33, which thereby is adapted to measure the fluid flow into the central pipe 20. The flowmeter 33 is also adapted to actuate an impulse sender and may, for example, be of the common water meter or rotary piston type, which comprises, as shown more fully in Figure III, an eccentric cylindrical rotor 36 and a reciprocable slide barrier 37 arranged to be forced against the rotor 36 by resilient means, such as a spring 39, acting on the outer end of the slide 37, which is positioned between the inlet and outlet conduits 34 and 35. Fluid entering the space between the rotor 36 and the flowmeter housing 33 from the inlet conduit 34 on one side of the barrier 37 and passing to the outlet conduit 35 on the other side of the barrier 37 causes the eccentric rotor 36 to rotate. The reciprocation of the barrier or slide 37 caused by the rotation of the eccentric rotor 36 cyclically operates an impulse sender switch or a clicker, in any suitable manner, such as by closing the electrical circuit through contact 38 and spring 39, to which are attached electrical conductors leading to the sending apparatus to be subsequently described.

The upper end of the reciprocable tubular element 30 extends through chamber 32 and flowmeter 33 therein and through a packing gland 40 into a motor chamber 41. Any suitable arrangement of power means may be provided in this chamber 41 for reciprocating at will the valve-carrying tubular element 30 and for pumping fluid into the expansible packers 15 through tubular element 30 and flexible conduit 59. For example, the tubular element 30 may be reciprocated by means of an electric motor 45 which rotates a worm gear 46 engaging a gear 47 which rotates a gear 48 engaging a rack 49 carried on the upper end portion of the tubular element 30. A second electric motor 55 operates a pump 56 having an intake 57 communicating with the outside of the housing 11. The pump 56 discharges into a flexible conduit 58 which connects to the upper end of the reciprocable tubular element 30.

The upper housing section 11d provides a water tight compartment for batteries 65, a relay set 66, signal-receiving means, such as a sound receiving cone 67, and signal-transmitting means, such as a transmitter cone or horn 68. The relay set 66, which may comprise suitable amplifying means, is adapted to actuate the pump motor 55 and valve-operating motor 45 in response to predetermined signals transmitted from the surface to the receiving cone 67. For this purpose, any suitable type relay system 66 may be used, and may comprise for example, an impulse-activated system such as is used in dial telephone systems or a magnet system which will set up or generate a current when a diaphragm vibrates, as described, for example, in

the Slichter Patent No. 2,191,121, which current may be used to operate a solenoid switch directly or through a suitable amplifying system. The actuating impulses may be of low frequency so as not to interfere with or to be actuated by the signal or impulse output of the transmitting cone 68 which may operate on a high frequency. If desired, the relay set 66 may comprise several tuned frequency circuits and thus be actuated by signals or vibration of different frequencies in a well-known manner, such, for example, as described in the Mattingly et al. Patent No. 2,255,721, while the transmitting cone 68 which reports the flow rate, may be operated at still other frequencies.

At the surface there may be provided suitable equipment, such as, for example, a portable unit mounted on a truck 85, as shown in Figure IV. The truck 85 may carry a small derrick 86, a drum 87 for the wire line 76, a vibration or sound transmitter 88 and receiver 89, together with amplifying and filter circuits and an instrument control board 90, and supply tanks 91 for acid and chalk suspension. Likewise, it is preferable to provide some means, such as a pump 92 which may be located at the well head for high pressure injection of flooding fluid, such as water, during the period of treatment.

In operation of the preferred embodiment of this invention, the assembled device comprising the housing 11 is lowered to the bottom of a borehole by means of a wire line 76, derrick 86, drum 87, etc. When the device reaches the desired depth, a particular sound, vibration, impulse or a series of impulses is initiated at the surface by means of the transmitting device 88, which travels down through the medium filling the borehole or the walls of the borehole, etc., to the receiving cone 67, and is conducted thereby to the relay set 66. In response to this particular signal, the relay set 66 selectively actuates the pump motor 55 and pump 56 in a predetermined manner, depending on the nature of the signal. On a first signal, fluid from the borehole is caused to be forced by the pump 56 through conduit 58, the tubular element 30 and the conduit 59 and thence into the packers 15, which are thereby expanded against the borehole walls to seal off or isolate a portion of the borehole.

The flooding or repressuring fluid, such as, for example, water, air, gas, etc., is injected into the borehole under high pressure by pump 92 and the main portion thereof flows down around the housing 11 and through the by-pass channel 13 and into the formation but not into that portion isolated between the expanded packers 15. A small portion of this flooding fluid flows through the conduit 34 into the flowmeter 33 and out through conduit 35 into the annular space between the tubular element 30 and the walls of the central pipe 20, and thence down into the housing member 11a and out through the perforations 14 into the formation sealed off between the packers 15.

It will be seen that there is only a small pressure difference across each packer, since the pressure of the flooding fluid in the space between the packers is only slightly lower than the pressure above and below the pair of packers by the amount of the resistance of the flowmeter and conducting tube 20. It is therefore only necessary to apply sufficient pressure to the flooding water to cause the operation of the flowmeter 33 and the chemical tanks 24 and 25.

The rate of flow of fluid into the sealed-off

zone is measured by the flowmeter 33 and the reciprocation of the dividing barrier 37 due to the rotation of the eccentric rotor 36 causes the horn or transmitter cone 68 to be actuated periodically. If desired, instead, the reciprocation of the barrier 37 may be arranged to produce clicks which can be amplified and conducted to the transmitter cone 68. The series of actuations of the horn or transmitter cone 68, as can be noted at the surface by receiver 89 and control board 90, will be fast if the zone is so permeable that it takes much fluid, or will be slow if the zone takes a small amount of fluid.

In the case where the flow is too great, the operator sounds another note or signal of particular frequency into the borehole, which causes the relay set 66 to energize the valve-operating motor 45 in the proper direction for moving the slidable tubular element 30 and valves 31 upwards into a position opening the ports 28a and 29a of the upper chalk-containing tank 24; the flow in the central channel 20 is thereby temporarily partially diverted through the chalk tank 24. By thus adding small increments of chalk to the fluid flowing to the sealed-off or isolated strata so as to build up a thin mud cake, and by continually observing at the surface the flow rate as reported by the flowmeter 33 and transmitter 68, the operator can adjust (that is, in this case, restrict) the flow rate to a desired medium value. After enough chalk suspension has been added to the stream of fluid to obtain the desired restricted flow rate into this stratum, another note is sounded at the surface to cause the motor 45 to return the valve-carrying element 30 to neutral position.

In the case where the flow is too small, that is, less than a predetermined medium rate, the operator initiates another particular signal by transmitter 88 at the surface, which signal on travelling down through the borehole and impinging on the receiving cone 67 causes the relay set 66 to energize the valve-operating motor 45 in the proper direction for moving the slidable tubular element 30 and valves 31 downwards into a position opening the ports 28b and 29b of the lower acid-carrying tank 25. The flow of flooding water or other fluid through the central channel 20 is thereby temporarily partially diverted into the acid tank 25. A slidable annular separator or spacer 80 above the acid in the acid tank 25 is preferably provided to prevent the water entering the upper port 28b from diluting the acid. The acid thus added to the flooding water passes into the section of the formation being tested and increases its permeability, allowing greater fluid flow thereinto. Preferably, the ports 28b and 29b are opened for short periods by first sounding a signal causing the valve-carrying element 30 to move downward and then closely thereafter sounding a signal causing the element 30 to move back to a neutral position. These signals may be repeated until enough small increments of acid are thereby injected into this isolated formation to increase the flow rate to the desired medium value while the flow rate is being continually measured and reported to the surface by the flowmeter 33 and transmitting cone or horn 68.

The packers 15 are then deflated by stopping or reversing the pump 56, which is accomplished by the relay set 66 in response to a particular note or set of signals issued by surface transmitter 88, and the device raised up to a position opposite the next higher stratum or sec-

tion of the borehole. The above operation of setting the packers 15 and determining the rate of flow of liquid into the formation between the packers 15 are repeated and thereafter the proper treatment with acid or chalk is applied, depending upon the permeability of this section of the borehole as measured and reported to the surface by the flowmeter 33 and transmitting cone 68. This series of steps is then repeated for each section of the open borehole into which fluid flows, until the flow rates into all the various porous strata have been adjusted to approximately equal values as may be indicated by the arrows of equal length in the treated lower portion of Figure IV. As applied to a whole oil field, the treatment of the injection wells in the above manner results in each injection well taking a balanced share of the flooding water, which desirable condition is represented by the uniformity of the dots signifying injection wells in the lower treated portion B as contrasted to the non-uniformity of the upper untreated portion A of the water flood lease map shown in Figure V.

It is readily apparent that various changes and modifications can be made in the above-described method and apparatus without departing from the spirit of the invention, one essential feature of which is the step of measuring the rate of flow of fluid through a porous formation traversed by a borehole at a point closely adjacent to said porous formation. Thus, for example, if desired, instead of controlling the above-described device by means of vibration or sound impulses transmitted through the medium filling the borehole, communication and control may be partially or completely accomplished directly by means of a cable containing insulated electrical conductors. Also, the present invention may be applied to other than injection wells of flooding systems. Thus, for example, the rate of flow of liquid from porous formations traversed by a borehole may be measured by placing expansible packers, a suitable flowmeter and reporting system, such as in the above-described flow adjusting device, at a position in the borehole with the flowmeter closely adjacent the point of efflux of fluid from the formation sealed off from the rest of the borehole between the two expansible packers.

I claim as my invention:

1. A method for substantially equalizing fluid flow into the various porous strata traversed by an open borehole of fluid injection wells of flooding or repressuring systems, comprising successively applying to portions of the borehole the treatment comprising the steps of packing off a desired vertical portion of the borehole, forcing a fluid into the borehole walls surrounding said portion, measuring the rate of said flow at a point adjacent said portion, indicating at the surface of the well said measured flow rate, and while maintaining said vertical portion packed off changing said flow rate by injecting into said portion of the borehole a fluid comprising a substance capable of modifying the resistance to fluid flow through the formation to a predetermined value whereby the resistances to fluid flow of the various portions of the borehole are substantially equalized.

2. In a device for adjusting the rate of fluid flow into the various strata traversed by an injection well of a flooding system, a housing adapted to be lowered into a borehole, a pair of axially-spaced expansible packer means mounted thereon for packing off a section of the forma-

tion traversed by the borehole, passage means in said housing opening outwardly above and between the packer means for directing fluid flow into said packed-off section of the formation, meter means in said passage means for measuring the flow of fluid therethrough, a reservoir in said housing containing a comminuted inert material, a second reservoir in said housing containing an acidic material capable of forming water-soluble salts with the earth formation, said reservoirs having openings communicating with said passage means, valve means closing said openings from said reservoirs to said passage means, and control means operable from the surface for actuating said valve means to open and close said openings for selectively adding the contents of one of said reservoirs to the fluid flowing into said formation.

3. In a device for adjusting the rate of fluid flow into the various strata traversed by an injection well of a flooding system, a housing adapted to be lowered into a borehole, a pair of axially spaced expansible packer means mounted therein for packing off a section of the formation traversed by the borehole, channel means in said housing opening above and below the packer means and adapted to allow the main portion of fluid flowing down through the borehole to bypass said packed-off portion, passage means in said housing opening outwardly above and between the packer means and adapted to direct a smaller portion of the fluid flow into said packed-off section of the formation, meter means in said passage means for measuring the flow of fluid therethrough and means for adjusting the flow characteristics of said formation comprising a reservoir in said housing containing a comminuted inert material, a second reservoir in said housing containing an acidic material capable of forming water-soluble salts with the earth formation, said reservoirs having openings communicating with said passage means, and means controlling the opening and closing of said openings for selectively adding the contents of one of said reservoirs to the fluid flow into said formation.

4. In a device for adjusting the rate of fluid flow into the various strata traversed by an injection well of a flooding system, a housing adapted to be lowered into a borehole, a pair of axially spaced expansible packer means mounted therein for packing off a section of the formation traversed by the borehole, channel means in said housing opening above and below the packer means and adapted to allow the main portion of fluid flowing down through the borehole to bypass said packed-off portion, passage means in said housing opening outwardly above and between the packer means and adapted to direct a smaller portion of the fluid flow into said packed-off section of the formation, meter means in said passage means for measuring the flow of fluid therethrough, means for indicating the measured flow rate at the surface of the well, and means for adjusting the flow characteristics of said formation comprising a reservoir in said housing containing a comminuted inert material, a second reservoir in said housing containing an acidic material capable of forming water-soluble salts with the earth formation, said reservoirs having openings communicating with said passage means, and means controlling the opening and closing of said openings for selectively adding the contents of one of said reservoirs to the fluid flowing into said formation.

5. In an apparatus for treating formations traversed by a borehole a housing adapted to be lowered into the borehole, at least two expansible packers vertically spaced from each other carried by said housing, means for expanding said packers into contact with the walls of the borehole, whereby a portion thereof is sealed off by said packers, passage means in said housing opening outwardly above and between the packer means and adapted to direct fluid flow into the sealed-off portion of the borehole between said packers, metering means in said passage for measuring said flow, means for conveying the indications of said metering means to the surface, a reservoir in said housing containing a substance capable of modifying the resistance to fluid flow through the formation, said reservoir having an opening communicating with said passage means, and means controlling the opening and closing of said opening for injecting said substance into the borehole between said packers.

6. In an apparatus for treating formations traversed by a borehole, a housing adapted to be lowered into the borehole, at least two expansible packers vertically spaced from each other carried by said housing, means for expanding said packers into contact with the walls of the borehole, whereby a portion thereof is sealed off by said packers, passage means in said housing opening outwardly above and between the packer means and adapted to direct fluid flow into the sealed-off portion of the borehole between said packers, metering means in said passage for

measuring said flow, means for conveying the indications of said metering means to the surface, a reservoir in said housing containing a substance capable of modifying the permeability of the borehole walls, said reservoir having an opening communicating with the passage means, valve means closing said opening from the reservoir to said passage means, and relay means actuated by an impulse transmitted from the surface for opening and closing said valve means to control the flow of permeability modifying substance through the opening in said reservoir to the sealed-off portion of the borehole between said packers.

7. A method for substantially equalizing fluid flow into the various porous strata traversed by an open borehole, comprising successively applying to portions of the borehole the treatment comprising the steps of packing off a desired vertical portion of the borehole, forcing a fluid into the borehole walls surrounding said portion, measuring the rate of said flow at a point adjacent said portion, indicating at the surface of the well said measured flow rate, and while maintaining said vertical portion packed off changing said flow rate by injecting into said portion of the borehole a fluid comprising a substance capable of modifying the resistance to fluid flow through the formation to a predetermined value whereby the resistances to fluid flow of the various portions of the borehole are substantially equalized.

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