Aug. 14, 1951 L. E. ELKINS 2,564,198

WELL TESTING APPARATUS

Filed Jan. 15, 1945 6 Sheets-Sheet 1

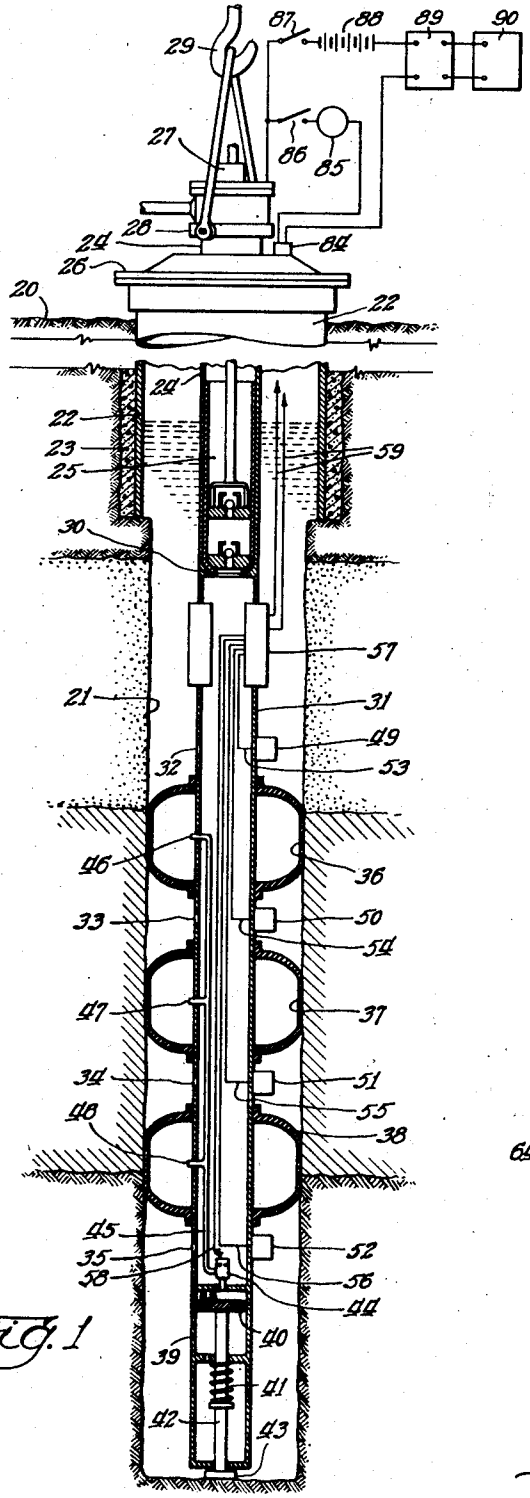


Fig. 1

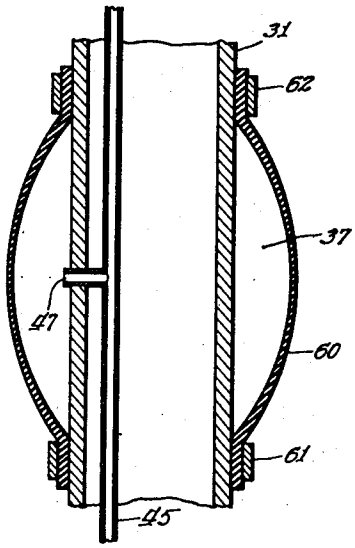


Fig. 2

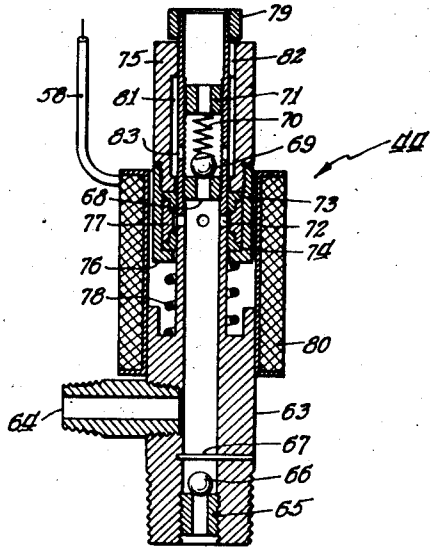


Fig. 3

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WELL TESTING APPARATUS

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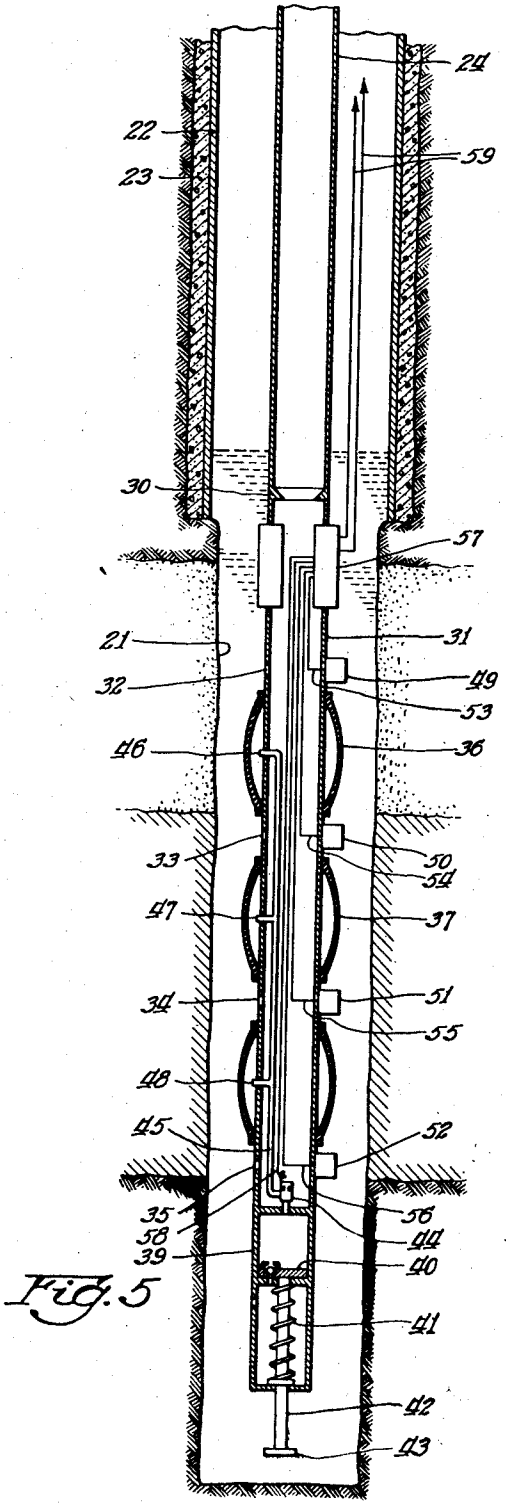


Fig. 5

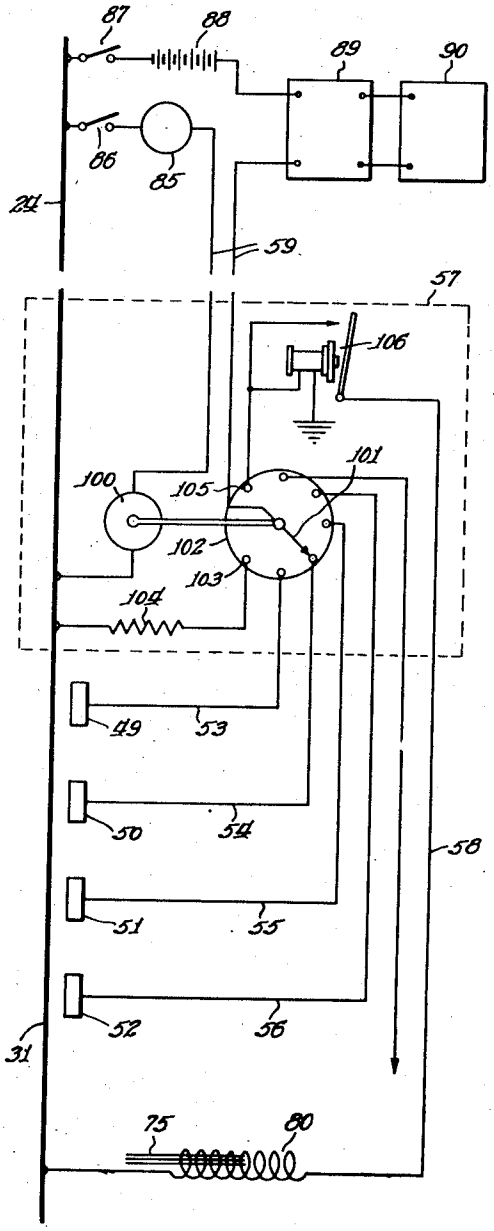


Fig. 4

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WELL TESTING APPARATUS

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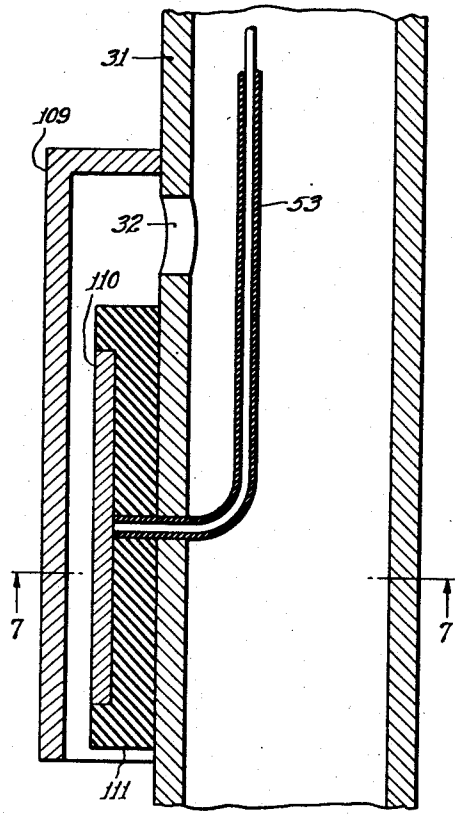


Fig. 6

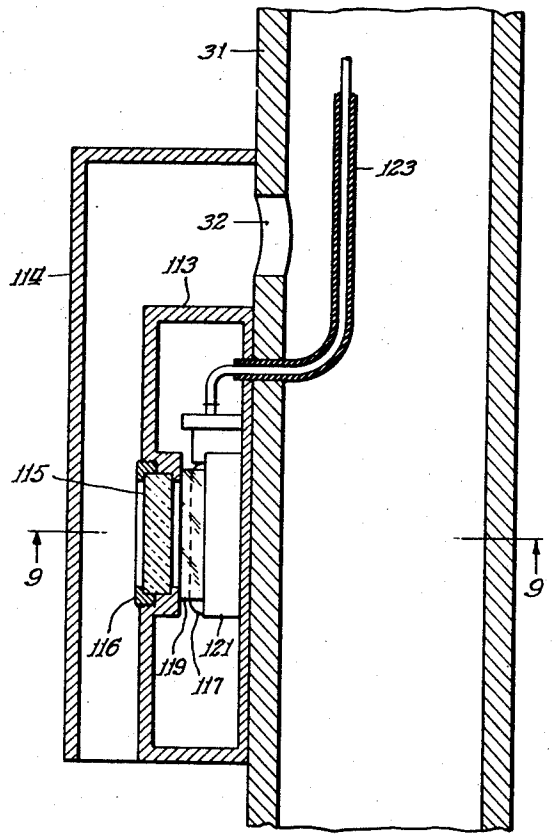


Fig. 8

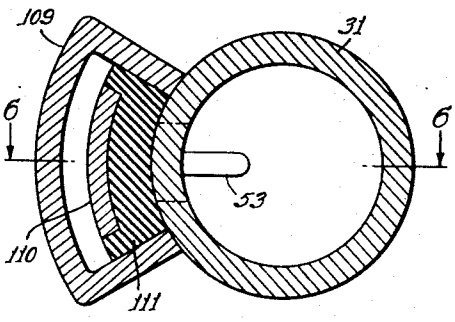


Fig. 7

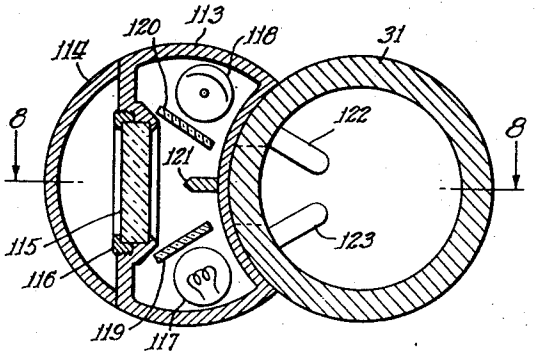


Fig. 9

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WELL TESTING APPARATUS

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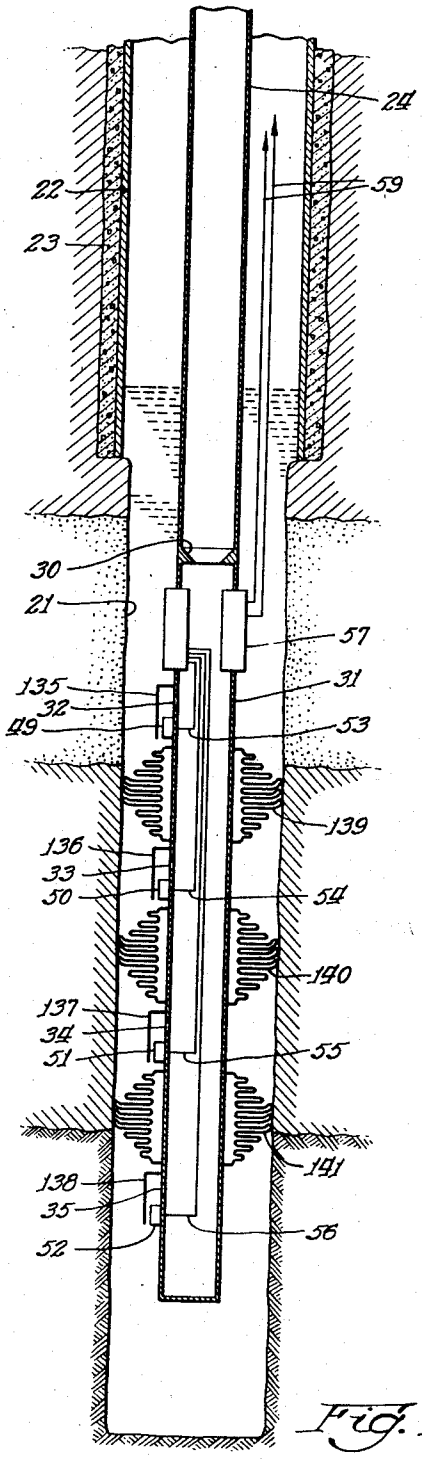


Fig. 12

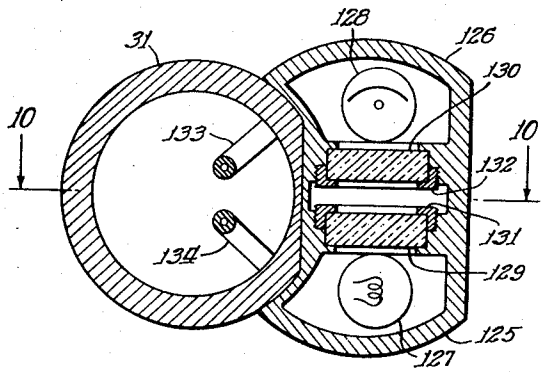


Fig. 11

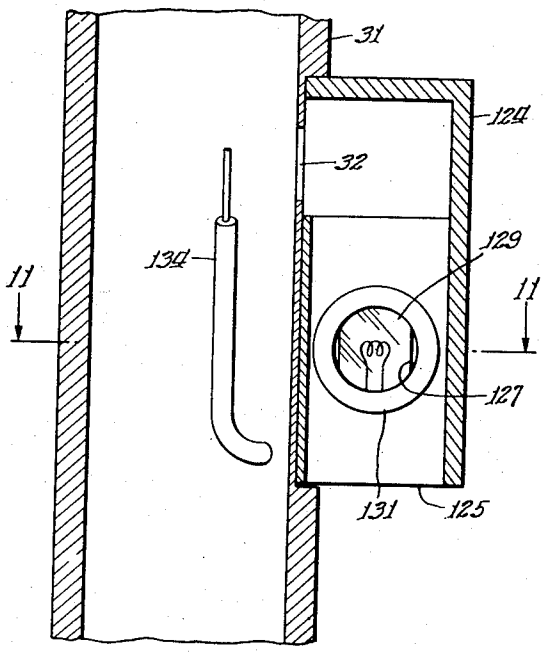


Fig. 10

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WELL TESTING APPARATUS

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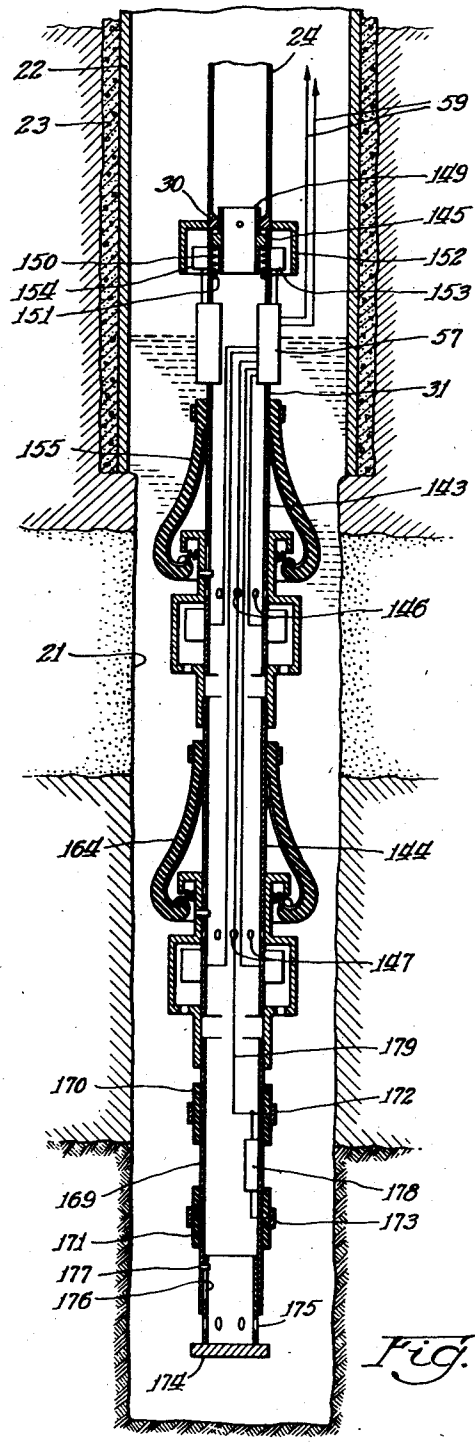


Fig. 14

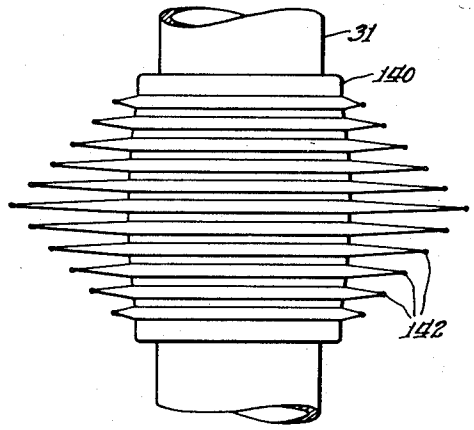


Fig. 13

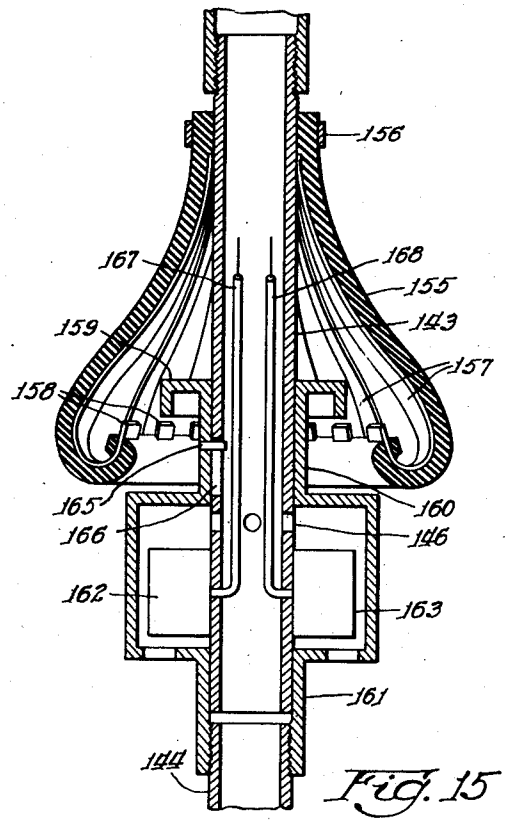


Fig. 15

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Aug. 14, 1951 L. E. ELKINS 2,564,198

WELL TESTING APPARATUS

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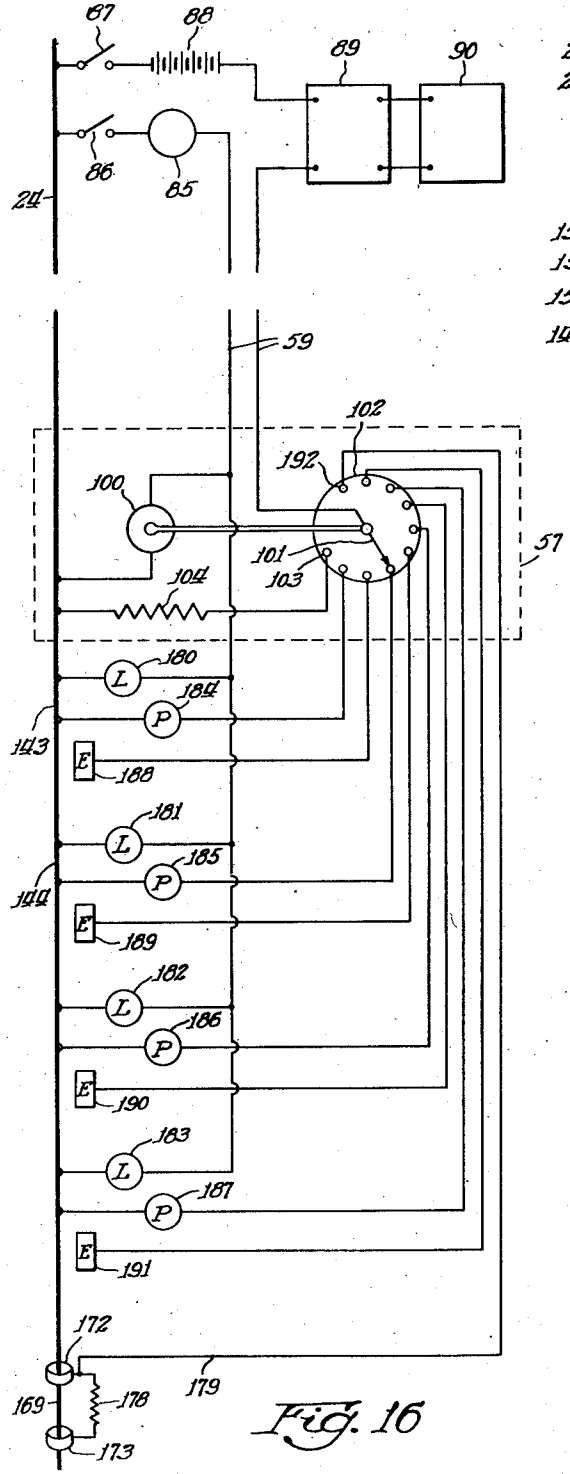


Fig. 16

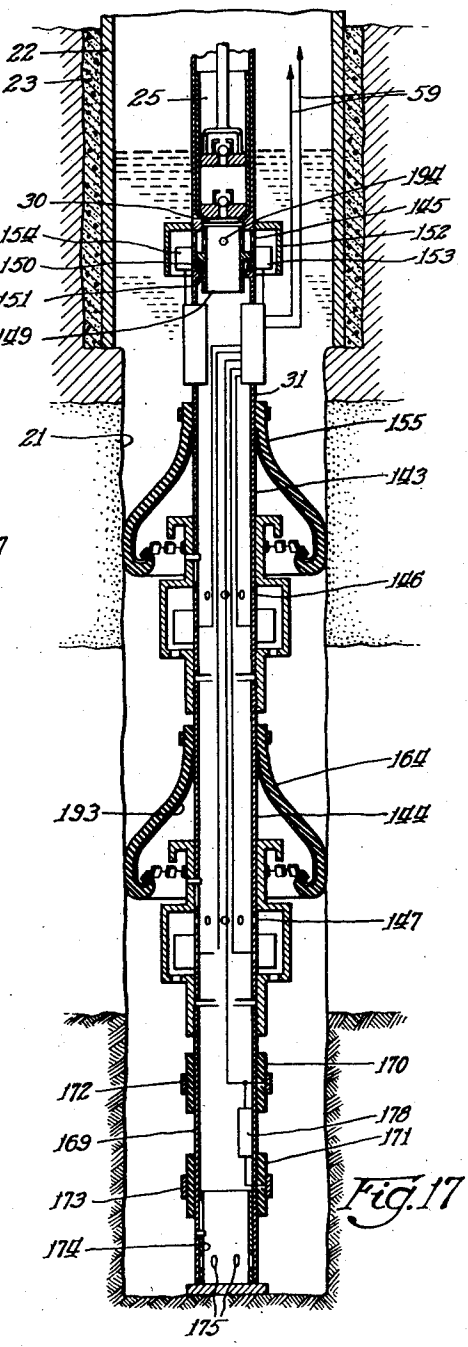


Fig. 17

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Patented Aug. 14, 1951

2,564,198

UNITED STATES PATENT OFFICE

2,564,198

WELL TESTING APPARATUS

Lloyd E. Elkins, Tulsa, Okla., assignor to Stanolind Oil and Gas Company, Tulsa, Okla., a corporation of Delaware

Application January 15, 1945, Serial No. 572,878

14 Claims. (Cl. 73—155)

1

This invention relates to the testing of wells and more particularly to locating the fluid-producing strata in oil and gas wells and determining the nature of the fluids produced. It is especially suitable for the testing of wells producing several different fluids simultaneously, such as gas, oil, and water or brine.

Various methods have been proposed for locating the permeable, fluid-producing zones of wells, particularly those producing brine. In many of these methods it is necessary to condition the well before testing by providing a column of fluid of known characteristics which are altered in a detectable way when fluid enters from the formation. This conditioning of a well is usually expensive, time-consuming, and uncertain, for the well must be shut in, circulating equipment and conditioning fluid must be provided, and in many instances an unknown amount of the conditioning fluid may penetrate the formations and subsequently mask the true nature of the fluids naturally produced thereby. Also the technique of handling a well filled with conditioning fluid is often exceedingly delicate. Too sudden pressure changes may upset the hydrostatic fluid balance and cause a rush of fluid either out of or into the formations so as to interfere with observation of the significant effects. These effects are, at best, transitory and subject to being disturbed by the process of observing them.

In other well-known methods of testing formations to determine their fluid-producing character, the section of the formation under test is first sealed off by packers or similar means, and fluids are then withdrawn from this sealed-off section for identification or analysis. Obviously, if the seal is imperfect, extraneous fluids may enter and mingle with the test fluids so as to give confusing results. It is extremely difficult to detect such contamination without the use of special precautions. In addition, if several strata in a producing zone are to be tested individually, it is usually necessary that the tubing and testing equipment be completely withdrawn after the testing of each such stratum. This adds considerably to the time and expense of making the tests and also results in an extended and undesirable interruption of the well production. Further, since a substantial pressure differential is ordinarily created between the sealed-off test section and the remainder of the producing zone, the design of packers to withstand this pressure differential and prevent leakage past the seal constitutes a problem that is often difficult of solution.

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For the testing of wells to determine their fluid-producing characteristics I have now devised an apparatus which overcomes most or all of these disadvantages. This testing apparatus is applicable to all types of wells without the need of any preliminary conditioning of the well fluids or prolonged interruption of the well production. Several adjacent strata in a producing zone can be individually tested at a single setting of the apparatus, and due to the fact that all parts of the producing zone are at all times in balanced equilibrium, the packers or elements designed to segregate production are not subject to measurable pressure differentials, and therefore the danger of contamination of fluid from one section of the zone by fluids from other sections is eliminated.

It is, therefore, a primary object of my invention to provide a novel and improved apparatus for determining the location and nature of fluid entries into wells. Another object is to provide an apparatus for testing a well causing a minimum of interference with the production of the well, and particularly an apparatus which requires no extended interruption of the well production for conditioning and testing the well fluids. A further object is to provide an apparatus for testing a well while it is producing at any desired rate, or at different rates, and either over a short or an extended period of time. A still further object is to provide a test apparatus in which the well is easily controlled, and in which pressure differentials throughout the producing section are kept low so that some of the usual causes of error are minimized or completely eliminated. Another object is to provide an apparatus for making a complete determination of the fluids and fluid-producing character of several adjacent well strata at a single lowering of the testing aparatus into the well. A further object is to provide an apparatus for determining the relative fluid permeability of each individual pay section as compared with that of other pay sections open to the well. Other and more detailed objects, uses, and advantages of the invention will become apparent as the description thereof proceeds.

In the appended drawings forming a part of this specification various specific embodiments of the invention are shown illustrating its application to the testing of wells. It should be kept in mind, however, that these drawings are for the purpose of illustration only, and that the invention is not limited solely to the employment of the exact apparatus and methods there dis-

closed. In these drawings, in which the same reference numeral in different figures is used to indicate the same or analogous parts;

Figure 1 represents in diagrammatic form a cross section of the earth penetrated by a well showing one embodiment of the invention in testing position in the well;

Figure 2 is a cross section of one of the sealing members of the apparatus of Figure 1;

Figure 3 is a cross section showing details of a valve used in the embodiment of Figure 1;

Figure 4 is a wiring diagram suitable for the embodiment of Figure 1;

Figure 5 is a diagrammatic cross section of the earth similar to Figure 1 showing the packers or sealing members in retracted position for raising or lowering of the apparatus in the well;

Figures 6 and 7 are, respectively, longitudinal and transverse cross sections through a fluid-conductivity type of identifier unit;

Figures 8 and 9 are, respectively, longitudinal and transverse cross sections through a fluorescence type of identifier unit;

Figures 10 and 11 are, respectively, longitudinal and transverse cross sections through a light-absorption type of identifier unit;

Figure 12 is a diagrammatic cross section of a well showing an alternative embodiment of the invention in testing position therein;

Figure 13 is an elevation of one of the sealing or packer members shown in Figure 12;

Figure 14 is a diagrammatic cross section of a well into which is being lowered a third embodiment of the invention, including means for carrying out relative fluid-permeability measurements on the well formations;

Figure 15 is a diagrammatic cross section showing certain details of one of the units making up the apparatus of Figure 14;

Figure 16 is a wiring diagram of the embodiment of Figure 14;

Figure 17 is a diagrammatic cross section of a well showing the embodiment of Figure 14 in testing position therein with the packer or sealing members expanded.

In brief, this invention comprises an apparatus for subdividing the portion of the well to be tested into a number of sections more or less isolated from each other and then identifying in place the fluids produced at each section before they become mixed with fluids produced at other sections. In other words, as fluids enter the well from the formations, they are obstructed from flowing along the well for any substantial distance, but are directed toward a single tubing port opening into each isolated section. One or more measurements of fluid character for purposes of identification are performed before the fluids are mixed inside the tubing with other fluids which have been withdrawn from the formations at other isolated sections.

It will be noted that while the well is being produced, each section being tested is in pressure equilibrium with all the others, since, after being identified or qualified as to type, the fluids from each section are connected and flow into a common stream within the tubing or flow string in the well. Thus, there is little or no tendency for fluid to migrate from one isolated section to another by leaking past the packer or sealing elements. This is in contradistinction to those usual methods in which an effort is made to seal off completely the section to be tested, in that here no significant pressure differentials are created which might cause fluid migration to or from each individual section. Instead, pressure differentials throughout the whole test zone are kept so small that even if the isolating seal between adjacent sections is not perfect, only a negligible amount of fluid will leak past it.

Referring now to Figure 1, there is shown drilled from the surface 20 a well 21, which may suitably have been equipped with a casing 22 cemented above the producing section at 23. Well 21 normally will be equipped with a tubing 24 and some means for controllably producing well fluids through this tubing such as equipment for flowing, pumping, swabbing, gas lifting, or the like. By way of illustration only, an insert-type pump is shown generally at 25. The surface equipment may consist of the usual tubing head 26 and stuffing box assembly 27 together with tubing elevator 28 coupled to a hoist 29 (not shown in detail) for raising or lowering the tubing. Below the tubing seat 30 for insert pump 25 is a tubular member 31 having openings at 32, 33, 34, 35. Fixed to member 31 between each of these openings are sealing or packer members 36, 37, 38, each of which may consist of an expansible resilient sleeve fixed at either end to member 31. At the lower end of member 31 is a pump consisting of cylinder 39 and piston 40 normally urged downward by a spring 41. Piston rod 42, of a length which may be changed to suit particular well conditions, is terminated in a foot piece 43 at its lower end. Connected to and communicating with cylinder 39 is a valve assembly 44 capable of performing several functions, which will subsequently be more fully described in connection with Figure 3. From the outlet of valve assembly 44 extends a tube 45 with branches opening at 46, 47, 48 to the inside of packer members 36, 37, 38, respectively. Fixed to tubular member 31 at points near the openings 32, 33, 34, 35 are fluid-identifying units 49, 50, 51, 52 which may be any one or more of several suitable types to be later described. For the present it is sufficient to state that almost any device capable of measuring or responding to a quality or property characterizing the fluids in which it is immersed might be adapted to this use. Insulated electrical leads 53, 54, 55, 56 connect each of these fluid-identifying units respectively to a switching unit 57, which is not shown in detail but which may suitably consist of a fluid-tight annular casing connected between the bottom end of tubing string 24 and the upper end of member 31, and in which is a rotary multipoint selector switch operated slowly through gearing by a small A. C. electric motor. Insulated lead 58 extends from one point of the rotary switch in switching unit 57 to an operating solenoid in valve assembly 44. From unit 57 an insulated two-conductor cable 59 extends upward to the surface electrical equipment.

In Figure 2 is shown in more detail the construction of one of the packing members 37 of Figure 1. A resilient sleeve 60 is clamped tightly to tubing member 31 at each end by metal bands 61, 62. It will be noted that sleeve 60 has a greater wall thickness at its ends than near the center of the sleeve. With this construction it is apparent that the application of fluid pressure through tube 45 and branch opening 47 will expand sleeve 60 more rapidly at the center than at the ends and thus will insure its making contact with and sealing against the walls of a well having irregularities or varying diameters at different points.

Referring now to Figure 3, there are shown

the design details of a valve assembly 44 which will perform the functions required in this embodiment. This consists of a central body member 63 having a side outlet 64 adapted to be connected to tube 45 of Figure 2. At the lower or inlet end of valve body 63 is a check valve consisting of a seat 65, ball 66, and retainer 67. Closing the upper end of valve member 63 is a relief valve consisting of seat 68 and ball 69 held down by a compression spring 70. The force of spring 70 can be adjusted as needed by a perforated abutting screw 71. In the sides of valve body member 63 are ports 72 which open to a space between packing cup washers 73, 74, fixed to a ferromagnetic sleeve 75 by a ferromagnetic cap member 76 threaded thereto. Packing cup washers 73, 74 are held apart by a spacer 77. Sleeve member 75 carrying packing washers 73, 74 is slidable on valve member 63, and is normally held in a position closing ports 72 by a spring 78 forcing it against an abutting ring 79. Surrounding the lower end of sleeve 75 and cap 76 is a solenoid 80 having a coil winding with one end grounded and the other end connected by insulated lead 58 to a contact in switching unit 57 as heretofore described in connection with Figure 1. Upon inspection it will be seen that by passing a current through solenoid 80 ferromagnetic cap 76 and sleeve 75 will be drawn downwardly, compressing spring 78, and uncovering ports 72. Fluid under pressure can then escape through ports 72, an annular space 81 between sleeve 75 and valve body 63, and out slots at 82, or through ports 83 and the hole in perforated abutting screw 71.

Through a stuffing box 84 shown in Figure 1 cable 59 is brought out to suitable surface electrical equipment. This may include a source of A. C. power 85 and switch 86 in series connected between tubing 24 and one conductor of cable 59, while a switch 87 and battery 88, in series with a recorder comprising units 89 and 90 are connected between tubing 24 and the other lead of cable 59. The tubing 24 thus forms between the surface and the well equipment a grounded conductor common to both the power and the recording circuits.

These same circuit elements are shown in Figure 4, which is a complete circuit diagram for this type of apparatus. In this figure tubing 24 and member 31 are shown diagrammatically at the left as forming one continuous conductor. The circuit elements within switching unit 57 of Figure 1 are those shown within the dotted enclosure of Figure 4, while those above the dotted enclosure are at the surface, and those below are fixed to the tubular member 31. Electrically connected between tubing 24 and the power lead of cable 59 is an A. C. electric motor 100 which, through mechanical gearing (not shown), drives slowly the moving contactor 101 of a rotary selector switch 102. Contactor 101 is connected to the recording circuit lead of cable 59, while the individual points of switch 102 are connected by insulated leads 53, 54, 55, 56 to identifier units 49, 50, 51, 52, here shown as fluid-conductivity cells, but which may be any other suitable type of fluid-identifying unit. One contact point 103 may advantageously be connected to tubing 24 through a known resistor 104, which then serves both as a means of correlating the switch contactor position with the record trace and as a means of calibrating the resistance of the recording circuit. Another

contact point 105 may suitably be connected through a time delay relay 106 to the insulated lead 58 extending to solenoid 80 of valve assembly 44. The delay of relay 106 is so adjusted that its contacts will not close during the normal time interval that contactor 101 is on point 105 as the switch is being rotated by motor 100.

A suitable recorder for use with this invention is the Westinghouse Type GH Pilotel Recorder which consists of an amplifier unit 89 (which may or may not be used, as required) and a pen-driving chart-moving unit 90. This instrument is adapted to trace on a moving chart strip a continuous line representing the variations with time of any desired electrical quantity such as current or voltage.

Upon inspection it will be seen that with this circuit arrangement both the switching and recording operations are completely at the control of an observer at the surface, since by closing either or both of switches 86, 87, the rotary selector switch 102 can be actuated at will, or a reading either taken on an identifier unit or omitted as desired. It should be noted that due to the presence of relay 106, it is practically impossible to actuate solenoid 80 of valve 44 (Fig. 3) inadvertently, since switch-driving motor 100 must be completely stopped with contactor 101 on point 105 for an appreciable time before the contacts of relay 106 close. Further, from the fact that one of the points of switch 102 is not utilized, it should be kept in mind that the use of four such units in Figures 1 and 4 is illustrative only, and more or fewer will be used when appropriate.

In Figure 5 is shown the apparatus of Figure 1 with the packers or sealing members retracted as it is being raised or lowered in a well. In operation this apparatus is lowered until foot member 43 strikes bottom, the length of piston rod 42 having been previously adjusted so as to place member 31 and its associated equipment at the proper level. Then by alternately raising and lowering the tubing 24 a few inches, cylinder 39 and piston 40 are reciprocated and through valve 44 and tubing 45 inflate the resilient packer sleeves 36, 37, 38. The compression of relief-valve spring 70 is adjusted so that the pressure inside packer sleeves 36, 37, 38 will be sufficient to inflate them into firm contact with the walls of the hole but insufficient to rupture them in the event the pump is operated longer than necessary. After the packer sleeves 36, 37, 38 have been inflated, well 21 is caused to produce fluids either by opening a control or choke valve if the well is a flowing one, introducing high pressure gas from the annulus into the fluid in the tubing in case the well is equipped for gas lifting, or by inserting and operating pump 25. By whatever method is appropriate, fluid is caused or allowed to enter the well from the formations, pass through tubing inlets 32, 33, 34, 35 and be withdrawn from the well through tubing 24. Closing of switch 86 permits power to be transmitted to motor 100, which rotates contactor 101. Then with switch 87 also closed, readings of identifier units 49, 50, 51, 52 may be transmitted to recorder 90 in succession. As well 21 is produced, fluids from the formations enter the spaces between and outside of resilient packer sleeves 36, 37, 38 and travel to each of the tubing openings communicating therewith. After a period of time, fluids originally present in the spaces between sleeves 36, 37, 38 will have been replaced by fluids from the formations at the correspond-

ing level, and a reading on each identifier unit will then be truly indicative of the nature of these latter fluids.

Since openings 32, 33, 34, 35 communicate with all of the sealed-off sections, it will be seen that there is little or no tendency to create large pressure differentials across any packer seal and thereby cause leakage past it. Normally the rate at which the well is produced and the time during which the production is continued should be sufficient to insure that the fluids filling all the spaces around packer sleeves 36, 37, 38 eventually are the same as in the formations outside. What is a proper rate and period of time will very from well to well depending, in part at least, upon the permeability of the formations exposed. Thus, it is apparent that a much longer time at a given rate will be required for sufficient fluid to enter from impermeable formations to displace those fluids originally surrounding the identifying unit than is required where the formations are highly permeable. If knowledge of the relative permeability of all the well formations is available, it can be used to great advantage in arriving at the optimum rate and duration of testing.

It is also possible to estimate when the well has been producing for a sufficient length of time by observing the changes with time of the fluids surrounding or passing each identifying unit. When no further changes are observed at a given unit, it is then safe to assume that the fluids surrounding it are truly representative of those in the surrounding formations.

Although for illustrative purposes Figure 1 shows subdividing the well into four test sections, this number will be varied to suit individual well conditions and to obtain the information needed. For maximum definition of fluid-producing strata the test portion of the well would be divided up into many short sections, while for other purposes adequate information could be obtained using only a few and longer sections. To go to the extreme, only one such packer might be used, and by providing ports both above and below it information could be obtained as to the fluids produced above and below the seal.

While only one such unit is illustrated in Figure 1, two or more different types of fluid-identifying units may be used simultaneously at the same tubing opening, depending on the completeness of the information which is desired. In Figures 6 and 7 is shown a unit for identifying fluids by their electrical conductivity. Covering the opening 32 in tubing member 31 is a hood 109, inside of which is an insulated metal plate electrode 110 set in a block 111 of suitable insulating material such as Bakelite. An insulated lead 53 brought out through the wall of tubing 31 and insulating block 111 connects electrode 110 with a terminal in switching unit 57 shown in Figures 1, 4, and 5. It will be apparent that with the application of voltage to electrode 110 a current will flow between it and hood 109, depending on the electrical conductivity of the intervening fluids being drawn to tubing inlet 32. Since the electrical conductivity of water or brine as found in oil wells is normally widely different from that of the hydrocarbons found therein, this unit is particularly adapted to differentiating between these substances.

In Figures 8 and 9 I have shown a fluid-identifying unit which may be used to detect the presence of crude oil as differentiated from gas and water. This may suitably comprise a fluid-tight housing 113 placed adjacent opening 32 in tubing 31 and surrounded by a hood or shield 114. In the wall of housing 113 is set a transparent disk 115 held in place by threaded ring 116 and sealed by a suitable thixotropic or semi-fluid sealing medium placed around its outer edge so as to prevent passage of fluid. Inside of housing 113 is an ultravoilet light source 117 and a photocell 118 with filters 119 and 120 interposed. A shield 121 prevents light from source 117 from falling directly on photocell 118. Filter 119 is one which preferably passes only ultraviolet light and absorbs or cuts off visible light. Transparent disk 115 should preferably be of quartz or a type of glass which will transmit ultraviolet light. Filter 120 is one which will exclude ultraviolet light while transmitting visible light. Insulated conductor 122 passing through the wall of member 31 and housing 113 connects photocell 118 with one point of the selector switch in unit 57 (Fig. 1 or 4), while a similar lead 123 connects light source 117 with the lead by which motor 100 is supplied with A. C. power. It will be seen that in operation this unit will indicate the presence of any liquid capable of fluorescing as it moves past disk 115 to reach opening 32. Since practically all crude oils fluoresce strongly in ultraviolet light, this unit is a sensitive detector for them.

In Figures 10 and 11 is illustrated an alternative identifying unit suitable for identifying fluids according to their ability to transmit or absorb light. Opening 32 in tubing 31 is here covered by a casing 124 forming part of two fluid-tight housings 125, 126 containing light source 127 and photocell 128 respectively. In the walls of these housings facing each other are set glass disks 129, 130 held in place by threaded rings 131, 132. It will be understood that a suitable thixotropic sealing medium surrounds glass disks 129, 130 to prevent fluid from entering the housings. Insulated lead 133 connects photocell 128 to a selector switch point in unit 57 (Fig. 1), while lead 134 supplies power to light source 127 from one side of A. C. motor 100 (Fig. 4) in the same way as with the unit of Figures 8 and 9. With this arrangement, in order for fluids to reach opening 32 they must pass between glass disks 129, 130 so that their light-absorbing properties can be measured. Although no special wavelength of light is specified, of which the absorption is to be measured in passing through the fluid between disks 129, 130, it will be apparent that by the interposing of proper filters, particular bands of wavelengths which are strongly absorbed by the fluids to be detected may be used and the selectivity of the unit increased accordingly.

While I have described in some detail certain convenient types of fluid-identifying units for use in this invention, many others might be devised which would work equally well by differentiating between other characteristics of the well fluids. Thus, it would be possible to distinguish between gas, oil, and water on the basis of viscosity, specific gravity, heat conductivity, acoustic wave velocity, and many other properties, and means for carrying out such measurement will occur readily to those skilled in the art.

For use in wells having walls that are fairly regular and uniform I have shown in Figure 12 an embodiment of the invention having a packer or sealing means different from and somewhat simpler in operation than that shown in Figure 2. In Figure 12 it will be noted that tubing member 31 is closed at the lower end and provided with inlet ports 32, 33, 34, 35 as before. Al-

though the identifier units 49, 50, 51, 52 could be mounted as in Figures 1 and 5, they are here situated immediately adjacent the openings and shields 135, 136, 137, 138 are placed over them so that fluids in order to get to openings 32, 33, 34, 35 must pass close by or through the identifying units. The packer or sealing members 139, 140, 141 are here made of some resilient material, such as a synthetic rubber which is oil resistant. As shown in more detail in Figure 13, each packer device 140 is formed of many thin flexible disks 142 of varying diameters, preferably tapered in thickness from the tubing radially out towards the outer edge which may be very thin. It will be apparent that upon lowering this device into a well, there will always be one or more of the flexible disks of the right diameter to close off the well by pressure against its walls. This will be aided by the pressure of disks of larger diameter, since the tapered construction will confine the flexing of each disk to a point near the wall of the well rather than allowing the disk to buckle near its base. Also, adjacent disks will tend to support each other and press their edges into firm contact with the sides of the well.

The operation of this embodiment is similar to that of Figures 1 and 5 except that in this case no inflation of the packer devices is necessary and all that is required is to lower the device in the well and start the well to producing, such as by opening a flow valve, admitting lifting gas, or inserting a pump on seat 30 and operating it. The wiring diagram of Figure 4 is applicable here with the only modification that the relay 106 and lead 58 to solenoid 80 can be omitted and the switch point 105 used for an identifying unit or left blank if not needed. Likewise any desired type of identifying unit may be used, alone or in combination with others. That is, two different types of unit may be used at the same tubing opening, or a different type of unit or combination of units could be used at different tubing openings. For example, in wells where it is known that water enters only at the bottom and gas near the top of the producing zone, the units near the bottom of the testing unit might be those particularly adapted to differentiating between water and oil, while those at the top would differentiate between gas and oil.

It should be noted that the placement of the identifying units within hoods or shields which force the fluids to flow by them to reach the tubing openings could be used advantageously on the apparatus of Figures 1 and 5, and such modifications of that embodiment are considered within the scope of this invention.

In Figure 14 I have illustrated another modification of my invention which provides for making a more complete survey of the well than do either of the embodiments heretofore described. In this the tubing member 31 is made up of individual sections such as 143, 144 and inlet ports are provided at 145, 146, 147, which are normally closed when the apparatus is run into the well. The upper ports 145 are located near insert pump seat 30 and are closed by a sliding sleeve-valve arrangement consisting of a sleeve member 149 urged upward by a coil spring 150 which rests on a ledge 151 inside tubing 24. A depending hood or shield 152 fixed to the tubing above ports 145 provides that fluids entering these ports must pass identifier units 153, 154.

A complete single apparatus unit, of which any desired number can be connected together to form the testing apparatus, is shown in more detail in Figure 15. This consists of the section of tubing 143 having ports 146, and fixed thereon a resilient umbrella-shaped packer sleeve 155 secured at its upper end to tubing 143 by a clamping band 156 and normally forced open at the bottom by steel leaf springs 157. When the device is run in the well, the steel springs 157 and resilient packer sleeve 155 are held away from the wall in retracted position by hooking the projecting ends 158 of springs 157 under a collar hook member 159, forming a part of a tubular sleeve 160, which may be an integral part of a housing 161 surrounding ports 146 and identifier units 162, 163. The lower end of housing 161 is of the same diameter as sleeve portion 160 to form a guide for the end of tubing section 143 and is threadedly coupled to a tubing section 144 forming a part of the next lower packer section corresponding to tubing section 143 and carrying packer 164 (Fig. 14). A pin 165 fixed in sleeve 160 cooperates with a slot 166 cut in tubing 143 to permit a limited relative movement of tubular section 143 and sleeve 160. Lowering tubing section 143 and packer 155 with respect to tubular sleeve 160 releases springs 157 and uncovers inlet ports 146 at the same time. Insulated leads 167, 168 connect the identifier units 162, 163 with the switching unit 57 shown in Figure 14.

Below the bottom tubing section 144 is a section of tubing 169 having insulating sleeves 170, 171 with metallic band electrodes 172, 173 mounted thereon. A resistance 178 is connected between electrodes 172, 173 by insulated leads, and the upper of these electrodes 172 is connected by an insulated lead 179 to one terminal in switching unit 57. The bottom end of tubing 169 is equipped with a sliding sleeve 174 having ports 175 and slot 176, which cooperates with a pin 177 set in tubing 169 to limit the relative vertical movement of valve sleeve 174 and tubing 169.

In Figure 16 I have shown an electrical wiring diagram suitable for use in this embodiment when two identifier units are being used at each set of tubing ports. For purposes of illustration it will be assumed that a fluid conductivity cell, and either a fluorescence or an absorption cell are being used together. In this circuit both the surface electrical equipment and that enclosed in switching unit 57 may be identical to that shown in Figure 4 except that the relay 106 is omitted. In parallel with each other and with motor 100, so as to be supplied with alternating current, are light sources 180, 181, 182, 183. Connected by insulated leads to the various stationary contact points of selector switch 102 are photocells 184, 185, 186, 187 and conductivity electrodes 188, 189, 190, 191 here shown connected with the switch points in alternating order, although this is immaterial so long as the exact order is known to the operator. One contact point 192 is connected by insulated lead 179 to metal band electrode 172.

With this equipment it is possible in a single survey of a well to obtain much more information about the fluid-producing character of the formations than with the other two embodiments. This is done by performing on the well during the insertion of the tubing 24 and its associated equipment a process of permeability logging by which the relative fluid flow resistance of the various formations can be determined. As previously pointed out, such information is of great value in the proper carrying out and interpretation of the subsequent fluid-character tests,

which primarily indicate the nature rather than the quantity of fluids produced.

At the start of the survey and before the tubing 24 has been lowered to bottom, the well is preferably filled to a point above the top producing formation with a liquid heavier than oil, such as water or brine. On top of this body of heavy liquid is a lighter liquid, for example, oil, immiscible and forming an interface with the brine. Because of the difference in electrical conductivity of the two fluids this interface can be located by the use of electrodes 172, 173, since if both electrodes are immersed in the non-conducting fluid, little or no current can flow through lead 179. If electrode 173 is immersed in the conducting fluid while electrode 172 is not, then resistance 178 is included in the circuit and an intermediate value of current will flow in lead 179; while if both electrodes 172, 173 are immersed in brine, resistance 178 is effectively bypassed and a maximum of current will flow. It is therefore possible to determine with this arrangement whether the interface between the electrically conducting and the non-conducting fluids, such as between the oil and the salt water, is below, intermediate, or above these electrodes.

Having once located the interface between the fluids in well 21, it is followed by means of electrodes 172, 173 while it is caused to move downward past the face of the formations by adjusting the input rates of oil through the annular space between casing 22 and tubing 24 and of salt water through tubing 24 and out ports 175. By correlating the position and movement of the interface with the input rates of the two liquids, the relative ability of those formations traversed by the well to take in fluids can be evaluated, and hence a relative permeability log can be deduced.

When by the injection of oil or water, or both simultaneously, the interface has been moved through the test region of the well, the introduction of these fluids is halted, and the apparatus is converted to one for multiple fluid-character measurements. Whereas in Figure 14 the inlet ports 145, 146, 147 were closed so as to direct fluid introduced into tubing 24 out through ports 175, it will be noted in Figure 17, which shows the apparatus set for a fluid-character test, that this situation is reversed, with ports 175 closed and the inlet ports 145, 146, 147 opened. This changeover is accomplished simply by lowering the apparatus and allowing it to rest upon the bottom of the well, since upon reaching the bottom, valve member 174 slides upward closing off ports 175. Upon further lowering, packing member 164 is first released and expanded by springs 193 to seal off against the wall of the well and ports 147 are opened. Further lowering releases packer member 155, and it too forms a seal against the well and ports 146 are opened. Inserting of pump 25 depresses sleeve valve 149 so that openings 194 therein register opposite the openings 145 in tubing 24. In this position this embodiment operates exactly as the embodiments of Figures 1 and 12.

It should be noted, however, that due to the fact that fluids foreign to the formations may have been injected into them during the permeability survey, the production of the well should be continued until practically all of the fluids forced into the formation have been withdrawn before taking any of the identifying unit indications as true. This will be indicated when a series of readings on the fluid-identifying units shows no further changes, and the well has therefore settled down to a steady-state production.

From the foregoing description it can be seen that by carrying out both the permeability and the fluid-character determinations as two parts of a single operation with the same apparatus, information of a far greater value is obtained than could be derived from either determination alone. That is, knowledge of the quantity of fluid entering a well at a given depth is only of limited value if it is not known whether the fluid is gas, oil, or water. Conversely, knowledge of the depths at which gas, oil, water, or mixtures of them enter, while in itself of very great value, is enhanced by knowing how much of each may be produced at each depth interval. With the complete information available from a single testing operation carried out as disclosed, remedial work to reduce gas-oil or water-oil ratios can be undertaken with assurance that the well will not be damaged. For example, plugging back to shut off water entering the bottom part of a well by dumping or squeezing cement in that part can be carried out in a single step because the operator will have determined in advance exactly which part or how much of the formation needs to be sealed off. This is a great improvement over the trial and error method now employed where several batches of plugging material are placed in succession, with a test following each to see if the quantity of water entering has been reduced.

With the average depth of oil wells generally increasing it has been observed that errors in depth determination can and do become great enough to be serious, and damage is done by treatments carried out at the wrong depth. However, when both the permeability and the fluid-character determinations are performed with the same tubing string and in the same manner disclosed, it is practically impossible for discrepancies in depth measurement to occur. Further, if the same tubing string is used for subsequent remedial work on the well, the practical advantage of the accurate depth determination is extended.

It is believed apparent that by this method and apparatus a test can be made of a portion of a well producing several different fluids without any appreciable interruption in the producing of the well. All that is normally required is an interruption for the short interval while the apparatus is being lowered to testing position, after which the normal well production can be continued. This apparatus can be controlled at will and left in place as long as necessary to identify fully the nature of the fluids entering the well at various levels. In the event the results at one setting or location of the apparatus are ambiguous or uncertain, as, for instance, if excessive leakage past one of the packers is suspected, the whole device can be lifted a few inches or feet and the measurements repeated or continued. It is deemed of major importance that the incentive to complete a test as rapidly as possible and often compromise on securing inferior data is almost completely lacking in this method of testing. The facility of repeating or prolonging a test contributes materially to obtaining the accurate data necessary for effective remedial work.

With the two apparatus embodiments first described this vertical shifting movement would be easy to perform, as in each case the pressure of

the packers against the walls of the well need not be so great as to anchor the apparatus in place. With the last embodiment described, however, it would be necessary to prevent the telescoping of the various individual sections from closing off the inlet ports when the device is lifted off bottom. This could be done in a variety of ways, such as providing L-shaped slots for the pins 177 and 165, so that by a combined lowering and rotating movement the various members could be telescoped and then locked in the desired position for testing. Thereafter they would remain in testing position whether the device was resting on bottom or not.

Although a switching device has been suggested for transmitting to the surface in succession the indications of the respective identifying units, it will be understood that a multiple-conductor cable could be provided such that each unit is connected individually to a surface indicating instrument.

Other variations and modifications can be utilized at the will of the operator, and numerous prior art devices can be modified to assist in carrying out this invention. It is to be understood that the invention is not limited to the particular apparatus described in detail in this specification but is best defined by the scope of the appended claims.

I claim:

1. Apparatus for testing wells comprising a tubing having a plurality of vertically spaced ports therein and adapted to be lowered into a well bore, means carried by said tubing for partitioning a producing zone of said well bore into a plurality of isolated sections with at least one of said ports opening into each of said sections, means attached to said tubing for simultaneously producing into each of said sections fluids from the well formations exposed in that section and for withdrawing said fluids through said ports into a single common stream within said tubing for removal from said producing zone, and fluid-testing means carried by said tubing to identify the fluids entering each of said sections from the exposed well formations therein before said fluids become commingled inside said tubing with fluids from others of said sections during the removal of the fluids from said producing zone.

2. Apparatus for testing wells comprising a tubing having a plurality of vertically spaced ports therein and adapted to be lowered into a well bore, partitioning means carried by said tubing for sub-dividing a producing zone of said well bore into a plurality of isolated sections with at least one of said ports opening into each of said sections, pump means within said tubing for simultaneously producing into each of said sections fluids from the well formations exposed in that section and for withdrawing said fluids through said ports into a single common stream within said tubing for removal from said producing zone, and fluid-testing means carried by said tubing to identify the fluids entering each of said sections from the exposed well formations therein before said fluids become commingled inside said tubing with fluids from others of said sections during removal of the fluids from said producing zone.

3. Apparatus for determining the location of ingress of each of a plurality of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, resilient well packer means carried by said tubing and disposed circumferentially between pairs of said openings, and fluid testing means fixed to the outside of said tubing near each of said openings for identifying said fluids before they become intermingled with fluids from others of said openings.

4. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of the well, radially expansible resilient well packer means carried by said tubing between pairs of said openings, means for expanding said well packer means into contact with the wall of the well, and fluid testing means on the outside of said tubing near each of said openings for sensing a characteristic of produced well fluids.

5. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into the well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, fluid expansible well packer means carried by said tubing between pairs of said openings, means for supplying fluid under pressure to expand said well packer means into contact with the wall of said well, and fluid testing means for sensing a characteristic of produced well fluids on the outside of said tubing near each of said openings.

6. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into the well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, radially expansible resilient well packer means carried by said tubing between pairs of said openings, releasable spring means for expanding said well packer means radially into contact with the walls of said well, and fluid testing means near each of said openings for sensing a characteristic of produced well fluids.

7. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, fluid testing means near each of said openings for sensing a characteristic of produced well fluids, and resilient well packer means carried by said tubing between pairs of said openings, each of said packer means comprising a plurality of closely-spaced parallel concentric flexible disks of varying diameters.

8. Apparatus for determining the location of ingress of each of a plurality of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, well packer means carried by said tubing between pairs of said openings, and fluid testing means on the outside of said tubing and immediately adjacent each of said openings for sensing a characteristic identifying the produced well fluids passing to said opening before intermingling with fluids passing to other openings.

9. Apparatus for determining the location of ingress of each of a plurality of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable

within a producing zone of said well, well packer means carried by said tubing between pairs of said openings, fluid identifying means adjacent each of said openings for sensing a characteristic of produced well fluids passing to said opening before intermingling with fluids passing to other openings, and means for directing the flow of said well fluids close to said fluid identifying means.

10. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, well-packer means carried by said tubing between pairs of said openings, and a plurality of fluid-testing means adjacent each of said openings and in a position to test said fluids before passage through said opening, one of said testing means at each opening being responsive to a first fluid property, and another of said testing means at said opening being responsive to a second fluid property, whereby fluids not identified by said first property may be identified.

11. Apparatus for determining the location of ingress of each of a plurality of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a single opening near the bottom end thereof, fluid identifying means adjacent said single opening, a plurality of testing units coupled together and to the bottom end of said tubing below said single opening, each of said units comprising a tubular member having an opening therein and carrying a single well packer means above said opening and fluid identifying means adjacent said opening for sensing a characteristic of produced well fluids before they enter said opening.

12. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into a well and having an initially closed opening near the bottom end thereof, fluid-testing means adjacent said opening, means for removing the closure from said opening, a plurality of units coupled together and to the bottom end of said tubing below said initially closed opening, each of said units comprising a tubular member carrying a radially extendable well-packer means and a fluid-testing means adjacent an initially closed opening in said tubular member below said packer, a tubular sleeve surrounding the lower portion of said tubular member covering said opening and holding said packer means retracted, the tubular sleeve of each unit being movable for a limited distance on said tubular member and being coupled to the tubular member of the next lower unit, said initially closed openings being opened and said packer means being extended on each unit in turn by the limited movement of each sleeve relative to the tubular member it surrounds, upon lowering of said tubing and coupled units, with the sleeve of the lowermost of said units in contact with the bottom of said well and the sleeves of successively higher units being held stationary by the sleeves of lower units having reached the limit of their permitted movement.

13. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, fluid testing means on the outside of said tubing adjacent each of said openings for sensing a characteristic of produced well fluids, well packer means carried by said tubing between pairs of said openings, said packer means being expansible into contact with the wall of said well by fluid pressure, means for supplying fluid under pressure to expand said packer means, and valve means for controllably releasing the pressure fluid to deflate said packer means.

14. Apparatus for determining the location of ingress and character of fluids produced by a well comprising a tubing adapted to be lowered into a well and having a plurality of longitudinally spaced openings therein disposable within a producing zone of said well, well packer means carried by said tubing between pairs of said openings, and means adjacent each of said openings for sensing the electrical conductivity of produced well fluids before said fluids become intermingled with the fluids entering said tubing at another of said openings.

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