June 26, 1945. C. S. SANDERS 2,379,106

DETECTING SALT WATER INTRUSION

Filed Aug. 30, 1941 2 Sheets-Sheet 1

Fig. 1.

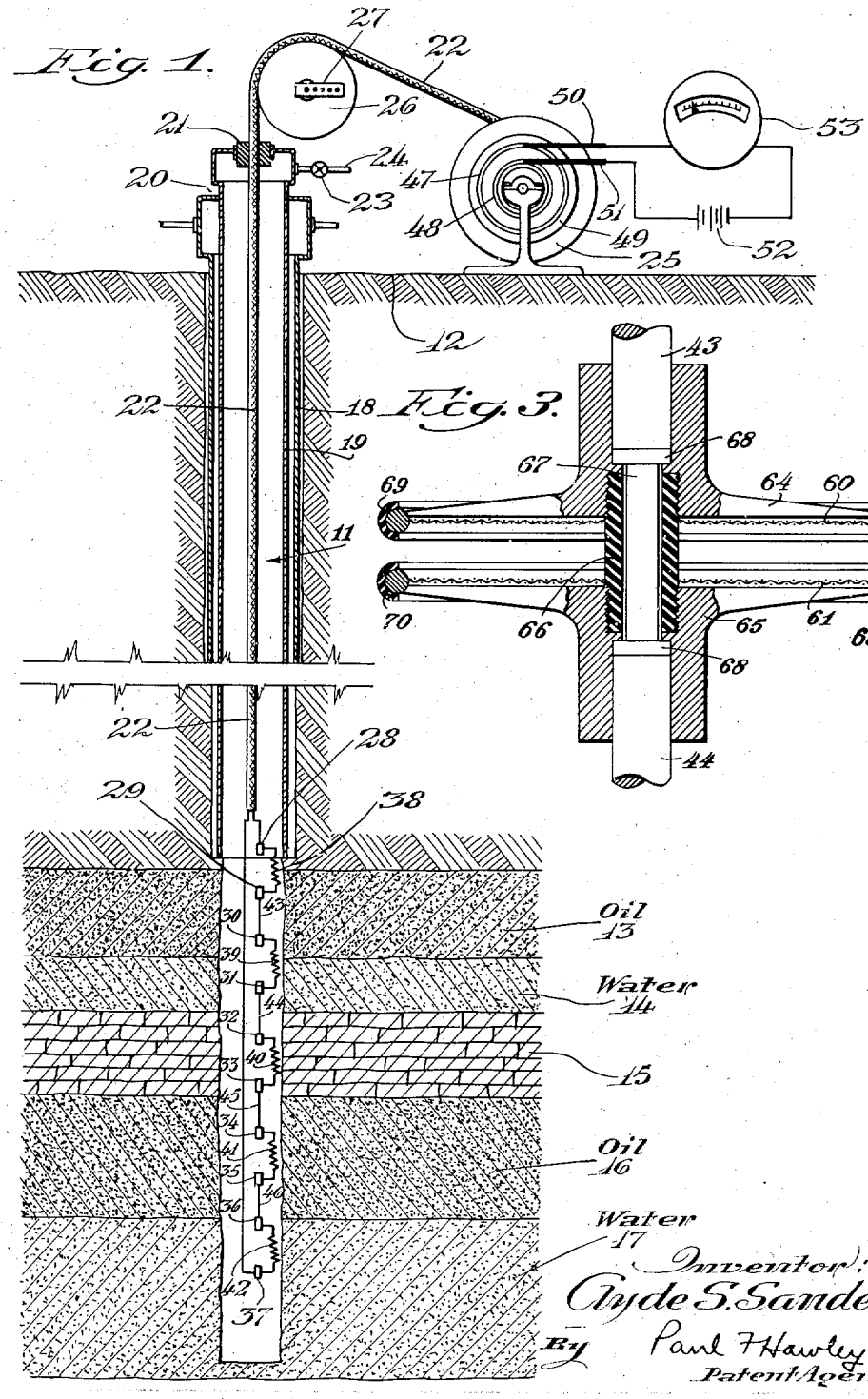


Fig. 3.

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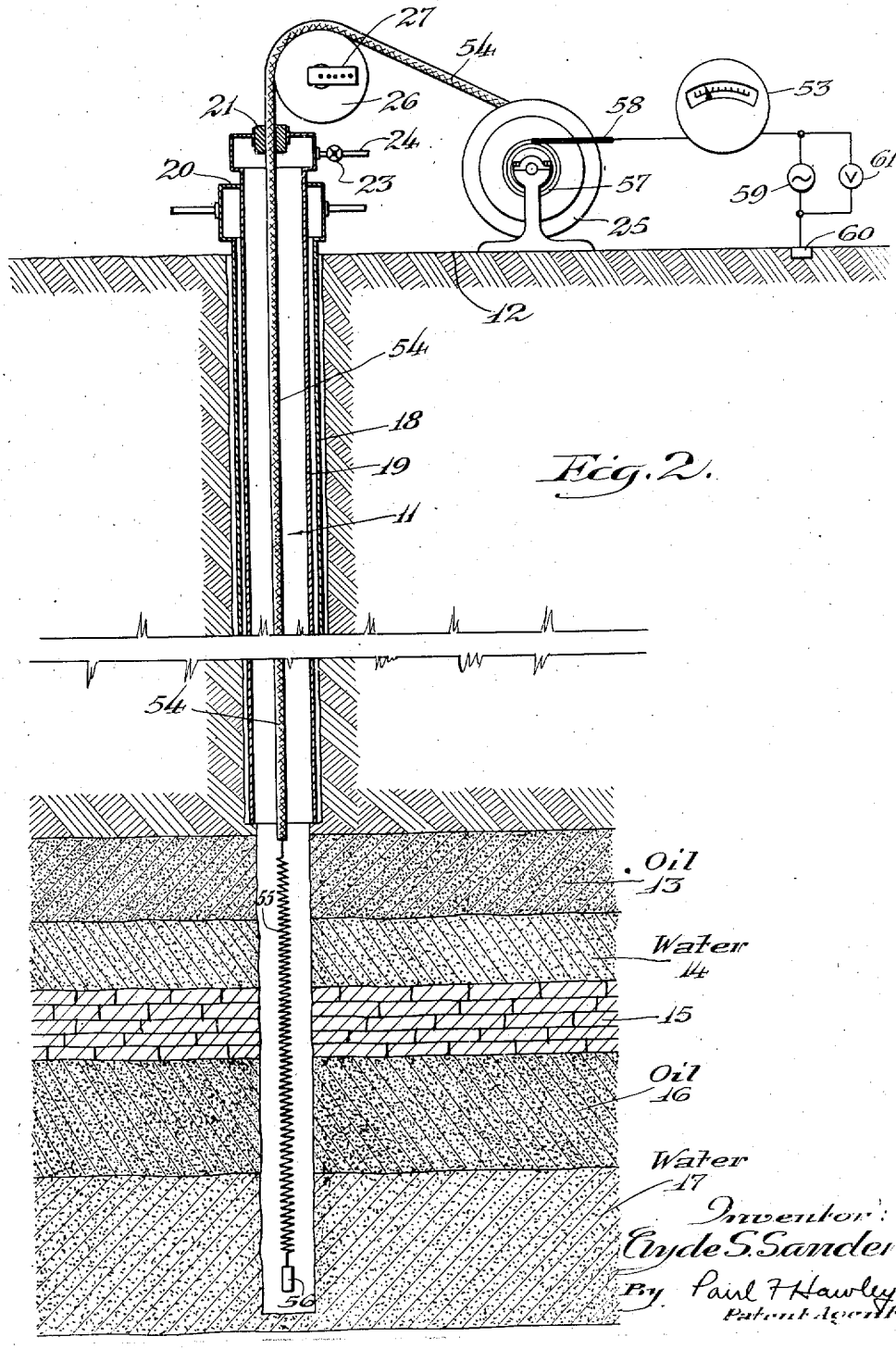


Fig. 2.

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Patented June 26, 1945 2,379,106

UNITED STATES PATENT OFFICE

2,379,106

DETECTING SALT WATER INTRUSION

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Application August 30, 1941, Serial No. 409,057

7 Claims. (Cl. 175—182)

This application relates to the art of detecting the presence of inflow of water in wells and more particularly to the determination of the zone or zones of ingress of water into wells. While this invention has particularly to do with the determination of ingress of water into oil and gas wells, it is not so limited.

In the operation of wells to produce various kinds of valuable products or in the drilling of test wells to determine the presence of such products it is often found that water enters these wells in more or less profusion from one or more permeable formations. Normally it is highly desirable to eliminate this water so that the substance being produced can be obtained at the well head with minimum dilution. This becomes of extreme economic importance in such matters as the operation of oil wells in which, unless considerable precautions are used, often the flow of oil from the well is not over a few percent of the total fluid produced. This problem occurs not only in wells from which the production has been almost exhausted, but also in the early production periods of wells and, in fact, may be a considerable problem as soon as a well is drilled. Considerable ingenuity has been employed in devising various means to shut off the flow of water. In recent years these methods have progressed to such a point that it is possible to shut off selectively various formations, for example, by the use of stage cement jobs and the like. However, it is obvious that the successful employment of any such method of shutting off the flow of water must be based upon the knowledge of the location of the water flow with considerable exactitude. For example, if a well is producing from two formations it is just as possible that water flowing into the well may come from the upper formation as from the lower.

Various methods have been employed in order to determine the zone or zones of water ingress into a well. Thus, for example, attempts have been made to utilize the data obtained from cores of the formations, i. e. by the location of permeable water sands. Attempts have also been made with somewhat greater success, to utilize the information gained from electrical logs of various types. However, this is often unsuccessful because no good method of determining permeability of the formations has as yet been set out and because the resistivity of a freely flowing water sand may be quite similar to that of a relatively impervious low resistance formation. Again, the effect of the infiltration of the fluid from the drilling mud into the various formations greatly affects the resistivities obtained so that a highly permeable oil sand may show the same electrical characteristics as a highly permeable water sand.

The best method of determination of the presence of water ingress into a well would seem to be the direct method, i. e. the detection of the water in the well as or just after it has seeped from the formation. In the past inventors have sought to determine the presence of this water in the well by various electrical sounding methods which in general involve measuring the resistivity of the fluid column in the well as a function of depth, but these attempts have been usually unsuccessful because the dropping of the sounding apparatus into the well disturbs the column of liquid and tends to spread out the water into a zone of considerable extent which, of course, causes erroneous results to be obtained.

I have discovered a method of determining the location of water ingress into a well which is simple, direct and expeditious, which involves only a single record and which can be carried out in any well regardless of the previous history of the well's operation. It may be applied to the determination of multiple points of ingress of water into the well as well as a single point of ingress. It is therefore an object of this invention to provide a method and apparatus for the determination of the location of water entering into a well.

It is a further object of this invention to provide a method and apparatus for the determination of water ingress into a well by means of which single electrical indication of the composite effects of water ingress at all points in the well is produced at the surface without the movement of apparatus through the well during the test period.

Another object of this invention is to provide such a method and apparatus in which a single electrical indication is produced at the surface regardless of the number of points of water entry while permitting the location of each point of water entry to be determined by the electrical indication. It is a further object of my invention to provide a method and apparatus for determining the change of level of water in the bore hole. Other objects and advantages of this invention will be apparent from the description immediately following.

In order to describe the principles upon which this invention is based in the clearest fashion, certain figures have been attached to this specification and made a part thereof which illustrate embodiments of my invention. It is to be un-

derstood, however, that there are further unillustrated embodiments of my invention which will be obvious to those skilled in the art, and that I do not intend to be limited to the embodiments illustrated. In these drawings the same number in various figures refers to the same or corresponding parts.

Figure 1 is a diagrammatic representation of a cross section through a portion of the earth penetrated by a well and certain items of equipment illustrating one embodiment of this invention; and

Figure 2 illustrates the same cross section of the earth and well shown in Figure 1 with another set of equipment illustrating an embodiment of my invention.

Figure 3 shows a cross section across one form of electrode station adapted for use in my invention.

In Figure 1 of this application I have shown a diagrammatic cross section of a portion of the earth's surface traversed by a well 11 extending from the surface of the earth 12. This well has penetrated in turn an oil stratum 13, a water stratum 14, an impervious stratum 15, an oil stratum 16, and a water stratum 17. As shown in the drawings, two strings of casing have been set in the well, a surface string 18 and a production string 19, the lower end of which is above the producing section of the well, i. e. the well section from which well fluids are obtained. In this case this section extends through the uncased portion of the well from the upper oil producing stratum 13 to the water stratum 17. At the surface, a conventional casing head indicated generally at 20 has been provided. If the well is a flowing well, an oil saver or stuffing box 21 is fitted on the casinghead, through which a cable 22 may be lowered without substantial loss of well pressure. If the well is not flowing no such equipment need be used. The production string of casing is connected through a valve 23 to a line 24 which may lead, for example, to the atmosphere or to an oil and gas separator, etc. All of this equipment with the exception of the cable is entirely standard.

It is presumed that it is known that water is being produced in the well. As a first step in shutting off this water, a string of tubing is lowered into the well (through the stuffing box if one is used) until the lower end is adjacent the bottom of the producing section, and a conditioning fluid is circulated in the well. This circulating fluid should be a liquid in the electrical resistivity of which differs markedly from that of salt water, and can, for example, be oil, drilling mud prepared from fresh water, fresh water, carbon tetrachloride or the like. It should either have a sufficent specific gravity so that the pressure head in the well is at least equal to the formation pressure or else extra pressure should be applied to it in a manner well known in this art, so that during the conditioning of the well no fluid from the formations can have ingress into the well bore. By the circulation of the fluid through the well the material originally present in the producing section at the start of the conditioning operation is replaced by a relatively uniform column of fluid of substantially uniform resistivity differing considerably from that of the connate water. The circulating pipe is then removed or at least a sufficient number of joints of this circulating pipe are removed so that the lowest end of this pipe is above the producing section.

While maintaining the hydraulic pressure on the producing section, the cable 22 is now lowered into the well. As shown in this figure, this is a two-conductor cable with each conductor suitably insulated. The cable is unreeled from a reel 25 and passes over a measuring sheave 26 as it is placed in the well so that the depth of the lower end of this cable is known at all times by inspection of the depth counter 27 actuated by revolution of the measuring sheave 26. Other types of depth measuring instruments may be employed if desired.

At the lower end of the cable 22 are a number of pair of electrodes exposed to the fluids in the well. In Figure 1 these are numbered from 28 to 37, respectively. Across pairs of electrodes such as 28 and 29, 30 and 31, etc. are connected electrical impedances which can, for example, be resistances 38 to 42, respectively, preferably insulated from the well fluids, though this is not essential. These pairs of electrodes are connected in series by insulated wires 43 to 46, respectively. The end electrodes are connected to the two cable conductors. While preferably the spacing between the electrodes forming a pair should be uniform, and while I prefer to have the spacing between adjacent pairs of electrodes to be equal, neither one of these conditions is at all requisite and any desired spacing may be employed between the electrodes in a pair or between adjacent pairs of electrodes. It is normally desirable in the case of small flows of water to have the two electrodes in a pair such as the electrodes 28 and 29 relatively closely spaced together, for example of the order of one-quarter inch to six inches. Spacing of two to twenty feet between pairs of electrodes is usually convenient, although these are not fixed limits.

No particular form is absolutely essential for these electrodes. I have found that one advantageous form consists of two circular sections of wire screen (window screen or the like) of the order of two inches or more in diameter, spaced approximately one-quarter inch apart and placed approximately horizontally in the well. In this embodiment of my invention it is advantageous when operating in a cased well producing through perforations to insulate the outer edges of the well electrodes and the wires between adjacent pairs of electrodes so that accidental short-circuits by contact with the well casing are avoided.

One such assemblage of electrodes 12 is shown in Figure 3. In this figure two circular sections of wire screen 60 and 61 are mounted on wire rings 62 and 63 respectively. These rings are in turn mounted on supporting metal spiders 64 and 65. The spiders are separated by a cylindrical piece of insulating material 66 within which is mounted impedance 67 furnished at the ends with metal ferrules 68 which make electrical connection between the impedance 67 and the spiders 64 and 65. The electrical connectors 43 and 44 are attached to the ends of the spiders 64 and 65, for example by conventional set screws (not shown). The wire rings 62 and 63 are surrounded by rubber protectors 69 and 70 which insulate the electrodes from accidental short-circuiting.

At the surface the ends of the cable stored on reel 25 are brought out to a pair of slip rings 47 and 48 on a disk of insulating material 49 mounted upon one end of the reel. Two brushes 50 and 51 bear upon the slip rings 47 and 48 and are connected together through a source of potential such as, for example, a battery 52 and a cur-

rent measuring device 53 which may be a meter, an oscillograph or other means of producing a visual indication of the flow of current, i. e. the impedance of the circuit. Any other potential source such as an alternating current generator could be used in place of the battery 52. If an A. C. source is used, condensers or inductances can be used instead of the resistances 38 to 42 described.

After the cable has been lowered so that the electrodes are spaced along opposite the producing section, the well is caused to produce a small amount of fluid from the various permeable formations by decreasing the well head pressure (for example by opening valve 23) if the well is a flowing well, or by bailing the well if it does not flow. As soon as water from a water-producing formation such as formation 14 or 17 is produced into the well it displaces the conditioning fluid in a relatively short period of time. The initial displacement occurs opposite the water producing formation or formations. Very shortly after this occurs the pair of electrodes nearest the water producing formation are short circuited by the relatively low resistivity water from the formation. This immediately changes the total impedance in the series circuit made up of the well electrode configuration, the cable, and the equipment at the surface, and accordingly changes the reading of the meter or whatever impedance measuring device is employed. At a short interval of time later the next pair of electrodes in the direction of flow in the water is similarly short-circuited, causing a second change in the reading of the meter, and so on. By this means the presence of water is detected, practically as soon as the water flow commences.

Preferably the impedances between the various pairs of electrodes are all of different magnitudes. Thus the change in current occasioned by the short circuiting of any one impedance will be different from that due to the short circuiting of any other impedance. By observing the magnitude of the initial change in current it is possible, knowing the depth of the various electrodes in the well, to determine the point of initial water entry. If there is evidence that the water flow is from two or more formations, such as shown in Figure 1, and that two pairs of electrodes may be short-circuited simultaneously, the impedances are chosen so that the sum of any two of such impedances, and preferably any number of such impedances, is not equal to the value of any one impedance. In this case the change in current due to the short-circuiting of two or more impedances is different from that due to the short-circuiting of any one impedance and the operator can immediately deduce the location of the two or more points of water entry. Any desired combination of impedances satisfying this condition can be used. One combination, for example, for the five impedances shown involves the use of impedances of 2,000, 4,000, 8,000, 16,000 and 32,000 ohms, respectively. In the case shown, using these impedances, one of the first two impedances shorted out is impedance 42 which causes a decrease in the total impedance of the series circuit of 32,000 ohms. The other of the first two impedances shorted out is impedance 39 which causes a decrease in the total series impedance of an additional 4,000 ohms. If the impedances are simultaneously short-circuited there is a total change of 36,000 ohms which results in a change in current which can not be mistaken for that due to the shorting out of either the 4,000 or the 32,000 ohm impedance alone. It is therefore apparent that from the reading of initial current and the initial change it is possible to determine the total impedance change and hence determine the location of all of the points of water entry or, more correctly, the location of the pairs of electrodes across which the initial short-circuits occur.

It is assumed in the above example that the conditioning fluid is of extremely high resistivity, for example oil, since it is obvious that at all times the fluid between adjacent electrodes furnishes a path for electric current which is in parallel with that of the corresponding impedance. If the conditioning fluid is water, it normally has a relatively low resistivity compared to that of oil, for example, and in such case much lower resistances or impedances should be used in the cable circuit. In one instance where the conditioning fluid had a resistivity of approximately 2500 ohm-inches and the salt water in the well was known to have a resistivity of approximately 12 ohm-inches, the following set of circuit impedances could be advantageously employed on a four-zone determination: 10.5, 22.2; 50, 133. The effective impedance across each pair of adjoining electrodes, such as electrodes 28 and 29 in Figure 1, taking into account the effect of the conditioning water, becomes in this case, 10, 20, 40 and 80 ohms respectively. When the well fluid forms a low impedance path across the top pair of electrodes, for example, this impedance changes from 10 ohms to slightly less than 1 ohm, thus causing a total change in impedance of the entire circuit of approximately 9 ohms or a percent change in the current in the circuit of 6%.

If the operator is interested in determining the change in water level with time he merely observes the change in the metered current with time since each change in current is uniquely related upon the particular pair or sets of pairs of electrodes that are short-circuited. If an oscillograph is used to record the current changes this record can be read in the same manner as the needle of the meter 53 can be observed, i. e. as a function of time.

If for any reason the spacing between pairs of electrodes is so great that the observer wishes to determine the location of the points of water entry closer than this spacing, the well is reconditioned and the electrodes are again located in the well, this time at a different position, preferably opposite the mid points between the locations of the previous observation, and again a single reading of the composite effect at all electrodes is made in the manner already described. The location of the points of water ingress, therefore, should be located with whatever degree of precision is required.

In Figure 2 I have shown an alternative set of equipment by means of which the biggest flow of water into the well can be determined. In this case a single conductor insulated cable is employed. The lower end of this cable terminates in a bare resistance wire 55 at the end of which can suitably be provided a weight 56 to stretch it the full length of the hole. Only a single slip ring 57 is employed and a single corresponding brush 58. The single brush 58 is connected in series with the meter 53 and a source of potential here shown as an alternator 59 to a ground connection 60. If desired a volt meter 61 can be connected across the source of potential, as shown.

The resistance wire 55 is lowered into the well opposite the producing section after it has been

conditioned and then the well is allowed to produce as before. The greatest source of water will cause the initial short circuit from the formation to a point on the resistance wire 55. The point at which the resistance wire 55 is short-circuited will hence depend upon the position in the well of this wire and the position of the water sand. The total resistance in the circuit at the instant of initial current change will be the relatively negligible cable resistance, the resistance of the ground between the ground connection 60 and the water in the well, and the resistance of the non-short-circuited portion of the resistance wire 55. Since this resistance wire is preferably much higher in resistance than the other resistances in the circuit, the total current immediately after the short-circuit will depend almost entirely upon the length of resistance wire above the point of contact with the salt water. By previous calibration, made, for example, by lowering the resistance wire 55 into a body of water, the current corresponding to a given length of non-short-circuited resistance wire can be determined. Therefore the initial reading of the meter, oscillograph, or other current measuring device taken in connection with the known depth of the end of the cable, indicates the depth at which the short-circuit occurred. In cases where there is one main source of water this apparatus operates as well as that shown in Figure 1 and gives a result which is usually equally accurate as to the depth of the body of water.

It will be noted that in the employment of this invention it is unnecessary to make a large number of individual determinations of the resistivity of the electrode configuration in the well since one single indication is produced of the composite effects occurring in the well. Likewise of interest is that the fact that the equipment in the well is not moved during the time that the readings are being taken so that there is no way by which electrode movement can spread out the flow of water into a zone which would obscure the sharpness of the determination of the water zone or zones.

Various modifications and adaptations of my invention will be apparent to those skilled in the art. The inherent novelty in this invention is best set forth in the appended claims.

I claim:

1. In apparatus for determining the location of at least one zone of water ingress into a well including means for displacing the fluids in said well by a conditioning fluid, an electric characteristic of which differs from the same characteristic of said water, an electric cable adapted to be lowered into said well, means for determining the depth of the lower end of said cable in said well, and means for permitting ingress of water into said well after the lower end of said cable has been disposed in the region to be investigated in said well, the improvement comprising a series-connected group of alternate impedances and connectors of considerable length, the ends of which group are connected to two conductors of said cable, each impedance in said group being of different value from that of any other impedance in said group and from any combination of said impedances, a plurality of pairs of electrodes equal in number to the number of said impedances, the electrodes of each pair being connected to the opposite ends of only one of said impedances, a source of potential, means for applying said source across the upper terminals of said cable, and means inserted in said circuit including said source, said cable, and said impedances for producing a visible indication of the flow of electric current in said circuit.

2. Apparatus for well logging according to claim 1 in which the electrodes of each of said pairs of electrodes are separated by a distance of from one-quarter to six inches and the separation between adjacent impedances is between two and twenty feet.

3. In a method for determining the location of a zone of water ingress through a permeable formation traversed by a well in which the fluids in a portion of said well including the region traversing said formation are displaced by a conditioning fluid, an electrical characteristic of which is different from the same characteristic of the water in said formation, so that the ingress of well fluids into said well is temporarily halted, in which a plurality of stationary fluid character-measuring zones substantially vertically displaced from each other are established at known depths within said well in the vicinity of said formation and in which formation fluids are caused to flow into said well, the improvement comprising producing an electrical effect at each of said zones, so varying said effect upon the ingress of formation water into said zone, that each of said effects, regardless of the conductivity of said water, is of different magnitude from that produced at any other of said zones and different from the simultaneous resultant of any plurality of said effects, varying the current in a single electrical circuit as the simultaneous resultant of the electrical effects at all of said zones, and producing a visual indication directly related to said variation in said current.

4. In apparatus for determining the location of a zone of salt water ingress into a well including means for stopping the ingress of fluids into said well and for displacing such fluids as are present in the producing section of said well by a conditioning fluid, means for lowering a testing apparatus in said well, means for determining the depth of said apparatus in said well and means for causing ingress of well fluids into said well, the improvement in which said apparatus comprises a plurality of substantially vertically spaced pairs of well fluids, a similar plurality of impedances each of which is connected across one of said pairs of electrodes, the value of each impedance being different from the value of all other impedances and from the sums of any plurality of other impedances in said circuit, a plurality of conductors so connecting one electrode of each pair to an electrode of an adjacent pair as to connect said impedances in series with each other to form a single series circuit, an electric cable two conductors of which are connected to the opposite ends, respectively, of said plurality of pairs of electrodes, and means located at the surface of the earth for producing a visual indication of the change in impedance of the series circuit including said cable and said impedances due to the formation of at least one low-resistance path across at least one of said impedances by ingress of salt water into said well.

5. In apparatus for determining the location of a zone of water ingress through a permeable formation traversed by a well including means for displacing the fluids in a portion of said well including the region traversing said formation by a conditioning fluid an electrical characteristic of which is different from the same characteristic of the water in said formation so that the ingress of well fluids into said well is temporarily halted,

means for disposing test apparatus in said well in a fixed position and at a known depth and in the vicinity of said formation, and means for causing ingress of well fluids into said well, the improvement in which the test apparatus comprises a plurality of electric fluid character-measuring stations each adapted to produce a change in an electric characteristic thereof upon the presence of water thereat, each of said stations having its characteristics so designed as to produce a change, the magnitude of which differs from the magnitude of the change at each of said other stations and from the magnitude of the sum of any plurality of changes at said other stations, a source of potential, current indicating means, and means for connecting in a single series circuit all of said stations, said source, and said indicating means, whereby the electric effect produced at each fluid character-measuring station changes upon arrival of water at said station, thus varying the indication of said indicating means.

6. Apparatus for determining the location of changes in the electrical conductivity of fluids at various points along the length of an oil well comprising a simple series electric circuit including one indicating means and a part which extends into the well and is adapted to be raised and lowered therewithin, said part of said circuit including in series connection at least two impedances and means electrically exposed to the well fluids at the ends of said impedances, said impedances having such different values that whenever one or more of said impedances are shunted by the presence of any conductive fluid which forms a low resistance path between the exposed means at the ends of said one or more shunted impedances, the identity of said one or more shunted impedances can be determined from said one indicating means.

7. A method for determining the location of changes in the electrical conductivity of fluids at various points along the length of an oil well comprising producing an electrical effect at each of a plurality of fluid character measuring zones in said well, so varying said effect upon the presence of a conductive fluid at each of said zones that each of said effects, regardless of the conductivity of said conductive fluid, is of different magnitude from that produced at any other of said zones and different from the simultaneous resultant of any plurality of said effects, varying the current in a single electrical circuit as the simultaneous resultant of the electrical effects at all of said zones, and producing a visual indication directly related to said variation in said current.

CLYDE S. SANDERS.

CERTIFICATE OF CORRECTION.

Patent No. 2,379,106. June 26, 1945.

CLYDE S. SANDERS.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, second column, line 47, claim 4, after "pairs of" insert the words --electrodes arranged for exposure to contact by--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 18th day of September, A. D. 1945.

Leslie Frazer

(Seal) First Assistant Commissioner of Patents.

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7. A method for determining the location of changes in the electrical conductivity of fluids at various points along the length of an oil well comprising producing an electrical effect at each of a plurality of fluid character measuring zones in said well, so varying said effect upon the presence of a conductive fluid at each of said zones that each of said effects, regardless of the conductivity of said conductive fluid, is of different magnitude from that produced at any other of said zones and different from the simultaneous resultant of any plurality of said effects, varying the current in a single electrical circuit as the simultaneous resultant of the electrical effects at all of said zones, and producing a visual indication directly related to said variation in said current.

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