

Dec. 24, 1968

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3,417,823

WELL TREATING PROCESS USING ELECTROOSMOSIS

Filed Dec. 22, 1966

2 Sheets-Sheet 2

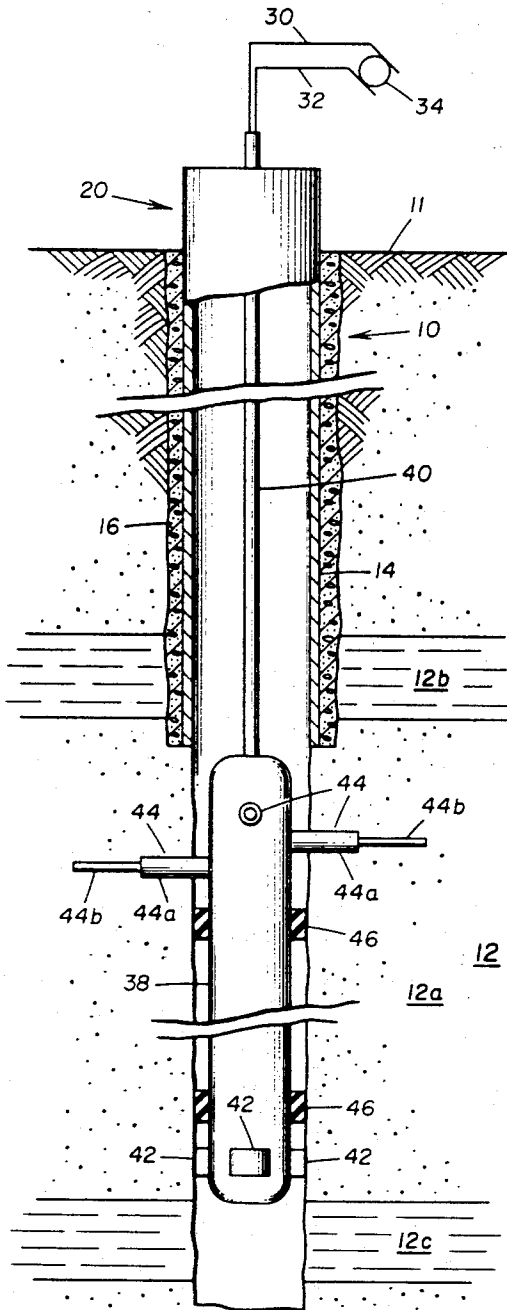


FIG. 2

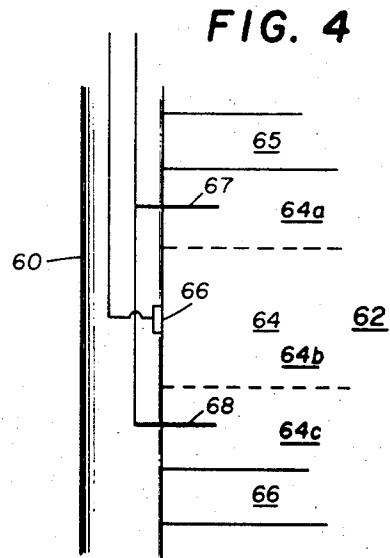


FIG. 4

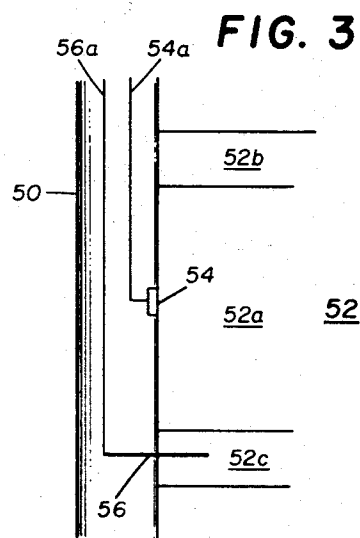


FIG. 3

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1

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WELL TREATING PROCESS USING
ELECTROOSMOSIS

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Filed Dec. 22, 1966, Ser. No. 603,810
11 Claims. (Cl. 166-45)

ABSTRACT OF THE DISCLOSURE

This specification discloses a formation treating process in which water adjacent a well is subjected to electroosmotic transportation. This is accomplished by establishing a unidirectional potential gradient between anode means in contact with the formation within an open flow interval and cathode means in contact with the formation at a location spaced from the anode means. Under the applied potential gradient water is electroosmotically transported in the direction of the cathode means, thus decreasing the water saturation adjacent the anode means.

This invention relates to the treatment of subterranean, hydrocarbon-bearing formations, and more particularly to a method of decreasing the water content of such a formation in the vicinity of a well therein by means of electroosmosis.

It has long been recognized that the movement of hydrocarbon fluids such as petroleum crude oil and gas through reservoir rocks is adversely affected by the presence of water in such rocks. For example, in a reservoir rock containing oil and water the effective permeability to oil varies somewhat inversely with the percent water saturation of the rock. Thus, by decreasing the water content of a segment of an oil reservoir, the rate at which oil may be moved therethrough under a given pressure gradient is increased. Similar considerations apply in the case of gas-water systems. Thus, the effective permeability to a gas of a section of reservoir rock may be increased by reducing the water saturation thereof.

In the injection or production of fluids through a well a disproportionately large amount of the energy needed to move the fluids through the reservoir is expended within the portion of the reservoir immediately adjacent the well. Accordingly, the injectivity or productivity of a well with respect to a given fluid can be greatly enhanced by increasing the effective permeability of the reservoir to such a fluid at the location of the well.

In accordance with the present invention, there is provided a new and improved method for increasing the effective permeability of a hydrocarbon-bearing formation adjacent a well therein through a unique application of electroosmosis.

Electroosmosis involves the movement of liquid through a porous solid by the application of an electrical potential difference. When a unidirectional potential gradient is established between two spaced electrodes in an earth formation, a liquid such as water in the formation will move through the formation in the direction of the cathode. The phenomenon of electroosmosis has seen a number of applications, particularly in the field of civil engineering. For example, in Casagrande, Leo, "Electro-Osmotic Stabilization of Soils," Harvard Soil Mechanics Series, No. 38, reprinted from Journal of the Boston Society of Civil Engineers, vol. 39, Jan. 1952, pp. 51-83, there is described several instances in which electroosmosis was used in the stabilization of soils. The utilization of electroosmosis in the production of oil also has been proposed. For example, Amba, S.A. et al., "Use of Direct Electrical Current for Increasing the Flow Rate of Reservoir Fluids During Petroleum Recovery," The Journal of Canadian Petroleum Technology, vol. 3,

2

Spring, 1964, pp. 8-14, describe the basic theory of electroosmosis as well as certain experiments relating thereto and propose generally its use in connection with increasing the flow rate of reservoir fluids during oil recovery operations. A more specific proposal for the use of electroosmosis in connection with petroleum recovery is described in U.S. Patent No. 2,799,641 to T. G. Bell. In this patent a unidirectional current, either pulsed or continuous, is passed between electrodes positioned in separate wells spaced from one another by distances of about 350-1000 feet or more. In the patent to Bell the production wells are used as cathodes under the theory that the applied difference in potential will cause oil to flow in the direction of the cathodes. The Bell patent does not appear to be directly concerned with the electroosmotic transportation of water and makes no reference to decreasing the water saturation of the formation at a given location.

The present invention is utilized in the treatment of a hydrocarbon-bearing formation penetrated by a well having an open flow interval and containing water in the vicinity of the open flow interval. The well is provided with anode means disposed in contact with the formation within the open flow interval and cathode means disposed in contact with the formation and spaced from the anode means. In carrying out the invention, a unidirectional potential gradient, either continuous or pulsating, is established between the anode means and the cathode means. Under the influence of this potential gradient water within the formation in the vicinity of the open flow interval is transported away from the anode means in the direction of the cathode means. Thus, the water content of the formation in the vicinity of the anode means is decreased and the effective permeability of the formation to hydrocarbon fluids is increased in the vicinity of the anode means. Preferably, the difference in potential between the anode means and cathode means is sufficient to establish a mean potential gradient between such means of at least 3 volts per foot.

For a better understanding of the present invention reference may be had to the following detailed description, taken in conjunction with the accompanying drawings in which:

FIGURE 1 is an illustration, partly in section, of a well and showing exemplary equipment for carrying out one embodiment of the invention,

FIGURE 2 is an illustration, partly in section, of a well and showing exemplary equipment for carrying out another embodiment of the invention,

FIGURE 3 is a schematic illustration of a further embodiment of the invention, and

FIGURE 4 is a schematic illustration of yet another embodiment of the invention.

With reference to FIGURE 1, there is shown a well 10 which extends from the earth's surface 11 and penetrates a subterranean, hydrocarbon-bearing formation 12. The formation 12 comprises an oil and/or gas reservoir 12a which typically may be of sandstone and overlying and underlying strata 12b and 12c, respectively, which typically may comprise relatively impermeable shale sections. As will be apparent from the description of the invention to be given hereinafter, the term "formation" is used herein and in the appended claims to include the overlying and underlying strata adjacent the hydrocarbon reservoir, as well as the reservoir itself.

The well 10 is provided with a casing string 14 which desirably extends into the formation 12, and preferably into the reservoir section 12a, and which is cemented within the well as indicated by reference numeral 16. The well also is provided with a tubing string 18 which is open at its lower end and extends from the bottom portion of the well to the wellhead 20 or surface of the well. A flowline 22 extends from the tubing 18 for the introduc-

tion and/or withdrawal of fluids. The bottom of the casing string 14 and the bottom of the well define the upper and lower boundaries, respectively, of an open flow interval 24 within the well. By the term "open flow interval" as used herein and in the appended claims is meant a section of the well which is open to the flow of fluids between the well and the surrounding earth material.

It will be understood that the well may be completed by other suitable techniques consistent with practice of the instant invention. For example, rather than the open-hole completion shown, the well may be cased and cemented to its total depth and the casing then perforated throughout an interval opposite the formation 12, such perforated interval defining the open flow interval within the well. In this case, of course, the hereinafter described electrode elements should be insulated where they pass through the casing. Also, the well may be provided with a plurality of casing strings such as a "conductor pipe," "intermediate string," and "oil string." Also, an uncemented slotted liner may be set within the well opposite the formation 12. These and other completion procedures are well known to those skilled in the art and, accordingly, will not be discussed further.

In accordance with the present invention, the well 10 is provided with anode means 26 and cathode means 28 supported on the tubing string 18 and disposed in contact with the formation 12. As shown in FIGURE 1, the anode system comprises four extensible anode elements 26a (of which three are shown) which are carried within a housing 26b which in turn is secured to the tubing string 18. The cathode system likewise comprises four extensible cathode elements 28a supported within a housing 28b. As will be understood by those skilled in the art, the cathode and anode systems may be run into the well with the tubing string 18 with the electrode elements 26a and 28a retracted within their respective housings. Thereafter, when the tubing string 18 is in place, the electrode elements 26a and 28a may be projected from the housings into contact with the face of the formation 12. Suitable mechanisms by which the electrode elements may be extended and retracted from their respective housings will be readily apparent to those skilled in the art and, accordingly, will not be described in detail. It will be recognized that such electrode elements may conveniently be operated electrically, mechanically or hydraulically.

The anode and cathode systems are connected via conductors 30 and 32, which are insulated from one another and extend through a suitable cable 33, to a D.C. power source such as a generator 34. Also, as shown in FIGURE 1, a packer 36 may be carried on the tubing string 18 and interposed between the electrode systems 26 and 28 in order to ensure that a short circuit between these systems does not develop within the well. In addition, a portion of the well between the cathode and electrode means may be filled with a suitable fluid of high dielectric characteristics.

After positioning the above-described equipment within the well 10, the generator 34 may be activated in order to establish a unidirectional potential gradient between the anode means 26 and the cathode means 28. Under the influence of this established potential gradient, water within the formation immediately adjacent the well 10 is electroosmotically transported away from the anode means 26 in the direction of the cathode means 28. Thus, the water content of the formation in the vicinity of the anode means is reduced and the effective permeability of the formation to hydrocarbon fluids at this location is increased. Accordingly, the injectivity or productivity of the well with respect to such hydrocarbon fluids is greatly enhanced.

While the present invention may be employed in the treatment of injection wells as well as production wells, it is a particularly useful tool for increasing the productiv-

ity of oil and/or gas production wells. Thus, after water has been electroosmotically removed from the vicinity of anode means 26, the well 10 may be placed on production. In this case, the hydrocarbon fluid within reservoir 12a is produced into the well below the packer 36 and recovered from the well via tubing 18. Of course, the well may be provided with suitable pumping equipment as may be necessary for effecting withdrawal of the produced fluids to the surface.

The hydrocarbon fluid produced into the well may be accompanied by water. In order to reduce this movement of water to the vicinity of the anode means 26a and also into the well, the invention may be carried out while the well is on production. Thus, fluid may be produced into the well while at the same time maintaining a potential gradient between anode means 26 and cathode means 28.

In theory, any potential gradient between the electrodes will result in some electroosmotic transfer of water. However, in order to achieve a significant increase in effective permeability, it is desirable as a practical matter to establish a difference in potential between the anode and cathode means of at least three volts for each foot of distance between such means. Preferably, the difference in potential between the electrode systems is equal to at least 30 volts for each foot of distance between these systems. A higher potential gradient may, of course, be utilized but appreciably greater voltages may become impractical from the standpoint of efficiency of power generation and transfer.

The potential drop within the formation is not linear since the current flow through the formation follows elliptical paths of increasing lengths. Also, a disproportionately large amount of potential drop occurs immediately adjacent each electrode element due to relatively high resistances developed at these locations. Thus, the potential gradient as determined by dividing the difference in potential between the electrodes by the distance between the electrodes does not correspond exactly to the incremental gradients which actually exist within the formation. Accordingly, since the quotient obtained by dividing the difference in potential by the distance is an average or mean value, it will be referred to hereinafter and in the appended claims as the "mean potential gradient."

As indicated above, a disproportionately high drop in potential occurs in the vicinity of each electrode. The actual drop experienced in the vicinity of the electrodes will depend upon factors such as the total potential drop between anode means 26 and cathode means 28; the nature of the electrolysis reactions occurring at the anode means 26 and the cathode means 28; and the current density, i.e., the total current divided by the area of the electrode through which it flows, at the anode means 26 and the cathode means 28. In view of these considerations, it usually will be desirable in carrying out the invention to provide a spacing between the anode means 26 and the cathode means 28 of not more than 15 feet. Preferably, the distance between the anode and cathode means will be within the range of three to ten feet in order to operate under reasonable power requirements and yet provide for significant electroosmotic transportation of water within the formation.

When, as shown in FIGURE 1, the electrical means are in contact with the face of the formation within the well, it is preferred to establish such contact throughout at least 50 percent of the periphery of the well. Thus, with respect to anode means 26, for example, the total cumulative length of the outer surfaces of electrode elements 26a should be equal to or greater than one-half of the circumference of the well 10 at the location of the anode means. It also is preferred in carrying out the invention to utilize electrode means which contact the face of the formation at points subtending an angle from the axis of the well of at least 180°. From an examination of FIGURE 1, it can be seen that this requirement is satisfied for both the an-

ode and cathode means. It will be recognized, of course, that only two diametrically opposed electrode elements, such as the elements 26a shown in FIGURE 1 in side elevation, are necessary in order to satisfy this requirement.

If desired, electrode systems may be used which contact substantially the entire periphery of the well. For example, the anode and cathode systems may take the form of formation packers which include a circular electrode ring disposed on the outer surface of the packing element so that the ring contacts the well wall when the packing element is expanded. Contact between the formation and the electrode systems also may be accomplished by means of a suitable liquid of high conductance. For example, the anode means may comprise a point electrode and a suitable conductive fluid such as mercury, the conductive fluid surrounding the point electrode and in contact with this electrode and the face of the formation. In this case, as in all others, care should be exercised in order to avoid a short circuit between the anode and cathode means within the well. Thus, these electrode systems should be isolated from one another within the well by means of suitable material exhibiting a significantly higher electrical resistance than the formation. As indicated previously, this can be accomplished by means of a packer such as that shown at 36 which is formed of a suitable insulating material.

In a well-completed open-hole with the casing string set to less than total depth, the casing itself may be utilized as a cathode. Thus, with respect to FIGURE 1, the cathode system 28 may be dispensed with and the negative pole of the generator 34 connected directly to the casing 14 which, as described above, defines the upper boundary of the open production interval 24. This embodiment of the invention is particularly advantageous in those instances where the casing string 14 is subject to severe corrosion since, in addition to reducing the water content in the formation in the vicinity of the anode means 26, the casing is afforded a measure of cathodic protection.

As noted previously, the unidirectional potential gradient established in accordance with the instant invention may be either continuous or intermittent. In some instances it may be desirable to apply a pulsating current of relatively low frequency, e.g., on the order of ten equal on-off cycles per minute, in order to offset the possible deleterious effects of the electrolysis reactions at the electrodes. Such pulsating current will tend to effect a time depolarization of the electrodes and thus reduce somewhat the disproportionately high potential gradient occurring in the immediate vicinity of the electrodes.

It also may be desirable to periodically reverse the polarity of the electrodes in order to accomplish similar results. For example, the electrode polarity may be reversed for a period of one minute once every ten minutes. The polarity may be reversed more frequently particularly where the reversed potential gradient is significantly less than the normal potential gradient. However, in any case the normal time-potential equivalent, i.e., the product of the difference in potential and the time during which such is applied, should, of course, be greater than the reversed time-potential equivalent and preferably greater by a factor of at least ten. It is to be recognized that by the term "unidirectional potential gradient" as used herein and in the appended claims is meant a continuous, pulsating, or periodically reversed potential gradient satisfying the above criteria.

As noted previously, the water content of the formation immediately adjacent the well is particularly critical since the greatest hydraulic pressure gradient involved in moving fluids from the well into the formation or from the formation into the well occurs within this area. In accordance with a preferred embodiment of the invention, the electroosmotic transportation of water away from the face of the wellbore is enhanced through the provision of cathode means which extends into the for-

mation to a location spaced laterally from the well. This embodiment of the invention will be described with reference to FIGURE 2 wherein like elements are designated by the same reference numerals as used in FIGURE 1.

With reference to FIGURE 2, there is shown an electrode carrier housing 38 which has been lowered into the well 10 by means of a cable 40. Carried within the housing 38 are a plurality of retractable anode elements 42 (similar to the anode elements 26a described above with reference to FIGURE 1) and a plurality of cathode elements 44. The carrier housing 38 also may be provided with one or more packers such as those designated by reference numeral 46, in order to center the housing within the well and also to provide for suitable insulation of the anode and cathode elements within the well. The cathode elements 44 are comprised of telescoping members 44a and 44b which may be extended from and retracted within the housing 38 through the provision of any suitable mechanism, as well be readily apparent to those skilled in the art. Each of the inner members 44b, which is telescoped within its respective outer member 44a, forms an electrode surface in contact with the formation 12. Preferably, the outer members 44a also form electrode surfaces in order to provide for as much surface area contact with the formation as possible. However, in certain instances, the members 44a may act as insulators with only the inner members 44b functioning as electrodes. Such an arrangement would be desirable for example where means such as packers 46 are not present to provide for insulation of the cathode and anode means from one another within the well. Also, such an arrangement is preferred where it is desired to reduce the water content of the formation immediately adjacent the well in the vicinity of the cathode means as well as the anode means.

The cathode elements 44 may extend into the formation 12 any suitable distance subject to the aforementioned criteria of electrode spacing and means potential gradient. Preferably, the cathode means will extend into the formation to a depth of at least six inches and, more desirably, the cathode means will extend into the formation to a depth of at least three feet in order to provide for appreciable movement of water away from the face of the formation. Also, it is preferred to position the cathode means such that it is in contact with the formation at points subtending an angle from the axis of the well of at least 180°.

It is to be recognized that the anode elements may be extended into the formation similarly as the cathode elements 44. However, it usually will be preferred to limit contact of the anode means to the face of the formation as shown.

The ease with which a fluid may be transported electroosmotically through a formation is largely independent of the hydraulic permeability of the formation. Thus, the so-called electroosmotic permeability of a formation exhibiting a hydraulic permeability of one millidarcy will be approximately the same as, or in some cases even greater than, the electroosmotic permeability of a formation exhibiting a hydraulic permeability of 100 millidarcies. In accordance with another embodiment of the invention, this characteristic of electroosmosis is utilized to advantage by positioning the cathode means in contact with a portion of the formation having a hydraulic permeability less than the portion of the formation in contact with the anode means.

This embodiment of the invention will be described with reference to FIGURE 3 which is a schematic illustration showing a well 50 penetrating a subterranean formation 52. Formation 52 comprises an oil and/or gas reservoir 52a and overlying and underlying shale beds 52b and 52c, respectively. As shown in FIGURE 3, the well is provided with anode means 54 and cathode means 56 which are connected through their respective

leads 54a and 56a to a suitable D.C. power source (not shown). As shown in the drawing, the cathode means 56 preferably extends into the shale section 52c although it may be in contact with the face of this section within the well similarly as the cathode means 28 described above with reference to FIGURE 1.

The embodiment of FIGURE 3 is particularly advantageous in the treatment of oil and/or gas producing wells. From the foregoing description it will be recognized that upon the establishment of a unidirectional potential gradient between anode means 54 and cathode means 56, the water within the formation adjacent the well will tend to migrate away from the anode means in the direction of the cathode means. Upon the continued application of the unidirectional potential gradient water will tend to accumulate within the relatively impermeable shale section 52c adjacent the cathode means 56. The movement of the water into the shale is largely irreversible by hydraulic means. Thus, even though a hydraulic pressure gradient is established from the formation into the well such pressure gradient will exert little if any influence upon the water transfetted to the shale section 52c. It is preferred in practicing this embodiment of the invention to place the cathode means in contact with a section of the formation exhibiting a hydraulic permeability which is less than that of the section contacted by the anode means by a factor of at least ten. Thus, if reservoir 52a contacted by anode means 54 is characterized by a permeability of ten millidarcies, the permeability of the shale contacted by cathode means 56 should not be more than one millidarcy.

In another embodiment of the invention, which is of particular utility with regard to oil producing wells, cathode means is disposed in contact with a gas zone and/or a water zone adjacent an oil zone. The positioning of the electrode systems in both gas and water zones in accordance with this embodiment of the invention is illustrated in FIGURE 4.

With reference to FIGURE 4, there is shown a well 60 which penetrates a subterranean formation 62. Formation 62 comprises a reservoir 64 and overlying and underlying shales 65 and 66, respectively. The reservoir 64 includes a gas zone 64a in the upper portion thereof, an intermediate oil zone 64b, and a water zone 64c in the lower portion of the reservoir. In accordance with this embodiment of the invention, anode means 66 is disposed in contact with the oil zone of the formation and cathode means 67 and 68 are disposed in contact with the gas zone and water zone, respectively. In carrying out this embodiment of the invention, a unidirectional potential gradient is established between anode means 66 and cathode means 67 and between anode means 66 and cathode means 68. Under the influence of this potential gradient, water within the formation will tend to migrate away from the anode means in the direction of the respective cathode means.

As water is electroosmotically transported into the gas zone 64a the effective permeability of this portion of the formation to gas is decreased. Thus, as oil is produced from zone 64b into the well 60, attendant gas production into the well, which oftentimes is undesirable, is decreased. A somewhat similar situation occurs with respect to the placement of the cathode means 68 within the water zone 64c. Thus, particularly where the unidirectional potential gradient is maintained concurrently with production of oil into the well 60, electroosmotic transport of water in the direction of the water zone 64c will tend to alleviate the coning of water into the oil zone and thence into the well. Such water coning is, of course, undesirable and oftentimes greatly reduces the oil production of a well.

FIGURE 4 also illustrates a desirable relative positioning of the electrode means regardless of the presence of gas and water zones adjacent an oil zone. Thus, even in

the absence of such gas and water zones the electrodes may be disposed as shown in FIGURE 4 with an anode element interposed between two vertically spaced cathode elements. Also, particularly, in relatively thick formations the invention may be carried out with a plurality of alternately positioned cathode and anode elements. Thus, with further reference to FIGURE 4, there may be provided a second anode element positioned below cathode 68 with additional electrodes added as desirable.

In most instances, water innately within a subterranean hydrocarbon-bearing formation will contain an electrolyte such as sodium chloride. However, the phenomenon of electroosmosis does not require an electrolyte and, in fact, the efficiency of the electroosmotic process may be enhanced by decreasing the concentration of electrolyte in the water. Stated otherwise, the electroosmotic flow rate for a given system and under a specified potential gradient varies somewhat inversely with respect to the specific conductivity of the water in the system. Thus, by decreasing the specific conductivity of the water, the rate of flow under electroosmosis may be increased.

In accordance with another embodiment of the present invention, these relationships are utilized to advantage by injecting into the formation water which is characterized by a lower specific conductivity than the water innately within the formation. By this procedure the average specific conductivity of the water within the formation immediately adjacent the wellbore is decreased. Thus, upon the subsequent establishment of a potential gradient between the electrode systems, the electroosmotic flow rate within the formation is enhanced.

From the standpoint of electroosmotic efficiency per se, it would be most desirable to utilize fresh water in the water injection step. However, it is to be recognized that in many instances this may be impractical or uneconomical and in accordance with the broad aspect of this embodiment of the invention any water having a lower specific conductivity than the innate formation water may be utilized in the water injection step.

It is preferred in this embodiment of the invention to introduce the water during the drilling of the well within the formation. This is accomplished by utilizing, during this stage of the drilling process, a drilling mud which comprises water of a lower specific conductivity than the water originally within the formation. As will be recognized by those skilled in the art, it is a conventional practice during such drilling operations to maintain a hydrostatic head on the drilling fluid at the depth of the formation which is greater than the formation pressure. Thus, some of the water contained within the drilling fluid will pass from the well into the formation. It is particularly desirable to utilize water of such lower specific conductivity during the drilling process since the introduction of water into the formation at this time is largely irreversible by hydraulic methods.

From the foregoing description, it will be recognized that the present invention provides a new and improved process for reducing the water content of a formation adjacent a point of production or injection. The application of the invention will result in some electroosmotic transportation of oil which may be present within the formation in the zone of treatment. It is believed that in many cases the movement of such oil under electroosmosis will be in the direction of the cathode. However, the efficiency of the electroosmotic process with result to oil normally will be much less than with respect to water. Accordingly, the movement of oil under electroosmosis will be in the direction of the cathode. However, the invention is applied in an oil production well.

Having described specific embodiments of the instant invention, it will be understood that further modifications thereof may be suggested to those skilled in the art, and it is intended to cover all such modifications as fall within scope of the appended claims.

What is claimed is:

1. In the treatment of a hydrocarbon-bearing formation penetrated by a well, said well having an open flow interval in said formation and said formation containing water adjacent said open flow interval, the method of:

establishing a unidirectional potential gradient between anode means in contact with the face of said formation in said well within said open flow interval and cathode means spaced from said anode means and extending into said formation to a depth of at least six inches from said formation face whereby water within said formation is electroosmotically transported in the direction of said cathode means thus reducing the water content of the formation in the vicinity of said anode means.

2. The method of claim 1 wherein said cathode means extends into said formation to a depth of at least three feet from said formation face.

3. The method of claim 1 wherein said anode means is in contact with the face of the formation at points subtending an angle from the axis of said well of at least 180° and said cathode means is in contact with said formation at points subtending an angle from the axis of said well of at least 180°.

4. The method of claim 3 wherein said anode means contacts the face of said formation throughout at least 50% of the periphery of said well.

5. In the treatment of a hydrocarbon-bearing formation penetrated by a well, said well having an open flow interval in said formation and said formation containing water adjacent said open flow interval, the method of:

establishing a unidirectional potential gradient between anode means disposed in contact with said formation within said open flow interval and cathode means spaced from said anode means and disposed in contact with said formation above said anode means whereby water within said formation is electroosmotically transported in the direction of said cathode means thus reducing the water content of said formation in the vicinity of said anode means.

6. The method of claim 5 wherein said well is provided with a casing terminating short of the bottom of said well and defining the upper boundary of said open flow interval, said casing comprising at least a portion of said cathode means.

7. The method of claim 5 wherein said cathode means comprises at least two vertically spaced cathode elements and said anode means comprises at least one anode element interposed between said cathode elements.

8. In the treatment of a hydrocarbon-bearing formation penetrated by a well, said well having an open flow interval in said formation and said formation containing water adjacent said open flow interval and having an oil zone and a gas zone disposed above said oil zone, the method comprising:

establishing a unidirectional potential gradient between anode means disposed in contact with said formation within said open flow interval and cathode means spaced from said anode means and disposed in contact with said formation within said gas zone

whereby water is electroosmotically transported in the direction of said cathode means to said gas zone thus reducing the water content of said formation in the vicinity of said anode means.

9. In the treatment of a hydrocarbon-bearing formation penetrated by a well, said well having an open flow interval in said formation and said formation containing water adjacent said open flow interval, the method of:

establishing a unidirectional potential gradient between said anode means disposed in contact with said formation within said open flow interval and cathode means spaced from said anode means and disposed in contact with a portion of said formation having a hydraulic permeability less than a portion of said formation in contact with said anode means whereby water within said formation is electroosmotically transported in the direction of said cathode means into said less permeable portion of said formation thus reducing the water content of said formation in the vicinity of said anode means.

10. The method of claim 9 wherein the hydraulic permeability of the portion of said formation contacted by said cathode means is less than the hydraulic permeability of the portion of said formation contacted by said anode means by a factor of at least ten.

11. In the treatment of a hydrocarbon-bearing formation penetrated by a well, said well having an open flow interval in said formation and said formation containing water adjacent said open flow interval, the method of:

during the drilling of said well into said formation, employing a drilling fluid comprising water of a lower specific conductivity than that of water inately within said formation and forcing said first-named water into said formation; and

establishing a unidirectional potential gradient between anode means disposed in contact with said formation within said open flow interval and cathode means spaced from said anode means and disposed in contact with said formation whereby water within said formation is electroosmotically transported in the direction of said cathode means thus reducing the water content of said formation in the vicinity of said anode means.

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STEPHEN J. NOVOSAD, *Primary Examiner*.

U.S. Cl. X.R.

175—65; 204—180

**UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION**

Patent No. 3,417,823

December 24, 1960

Sam R. Faris

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 27, cancel the heavy line and insert the same after line 26. Column 2, line 25, "unidirectoinal" should read -- unidirectional --. Column 4, line 31, "sine" should read -- since --. Column 5, line 56, "sinificantly" should read -- significantly --. Column 6, line 20, "well" should read -- well --; line 39, "means" should read -- mean --. Column 7, line 22, "transfetrre" should read -- transferred --. Column 8, line 66, "result" should read -- result --; line 69, "will be in the direction of the cathode. However," should read -- should be of relatively small significance where --; line 75, before "scope" insert -- the --.

Signed and sealed this 17th day of March 1970.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents