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Kern

[11] **3,862,662**

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[54] **METHOD AND APPARATUS FOR ELECTRICAL HEATING OF HYDROCARBONACEOUS FORMATIONS**

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[52] **U.S. Cl.** **166/248**

[51] **Int. Cl.** **E21b 43/24**

[58] **Field of Search** 166/248, 302, 65, 258

[56] **References Cited**

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3,149,672	9/1964	Orkiszewski et al.	166/248
3,417,823	12/1968	Faris	166/248
3,605,888	9/1971	Crowson et al.	166/248
3,620,300	11/1971	Crowson	166/248
3,642,066	2/1972	Gill	166/248

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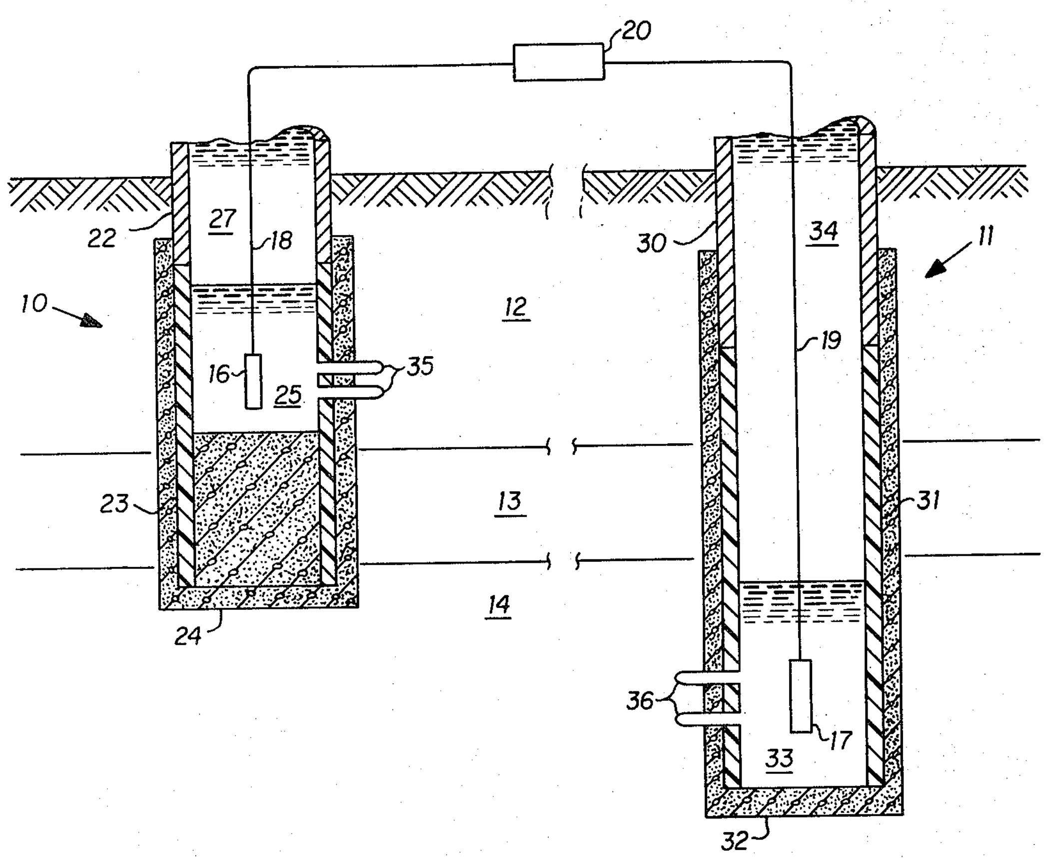
[57] **ABSTRACT**

A method and apparatus for electrically heating a subterranean hydrocarbonaceous formation situated between adjacent upper and lower layers having substantially lower resistivity than the formation itself. A pair of wells are drilled through the formation spaced apart at a preselected interval. A pair of electrodes are placed within the respective wellbores, one electrode being positioned above the formation in electrical contact with the upper layer, the other being positioned below the formation in electrical contact with the lower layer. A potential difference is established between the two electrodes causing an alternating current to flow through the formation along a plurality of laterally separated paths adapted to heat the formation with substantial uniformity between the two wellbores.

25 Claims, 6 Drawing Figures



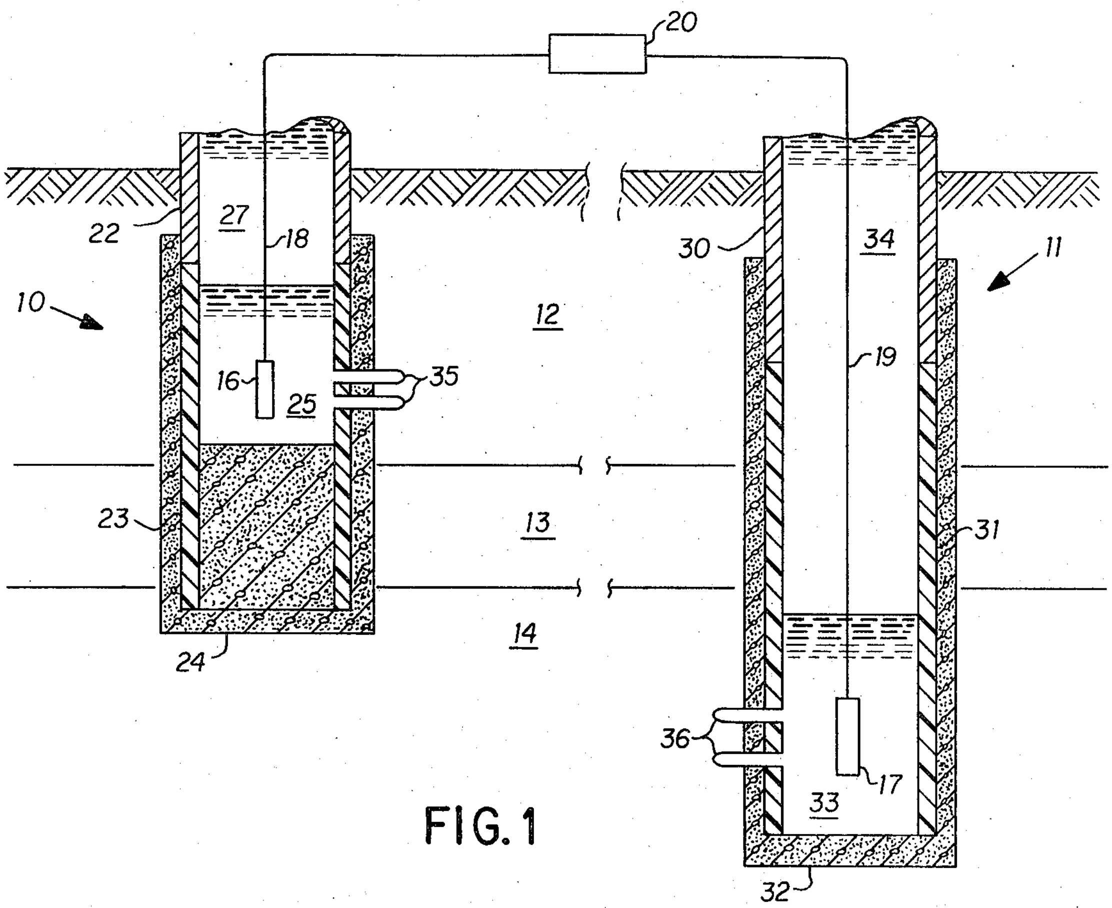

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FIG. 1

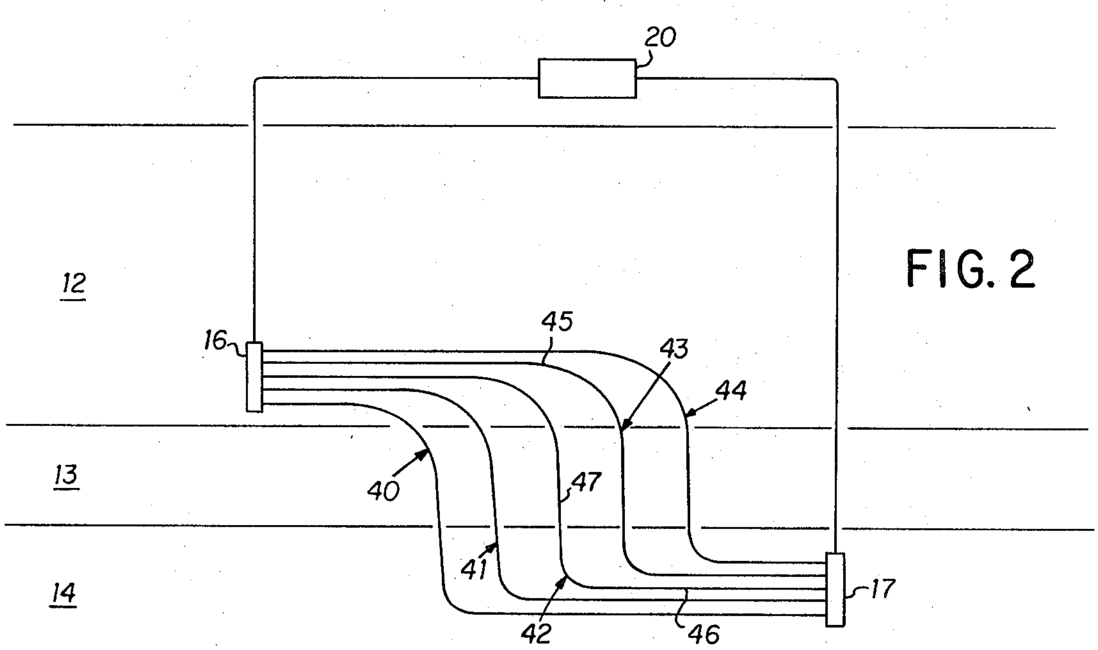
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FIG. 2

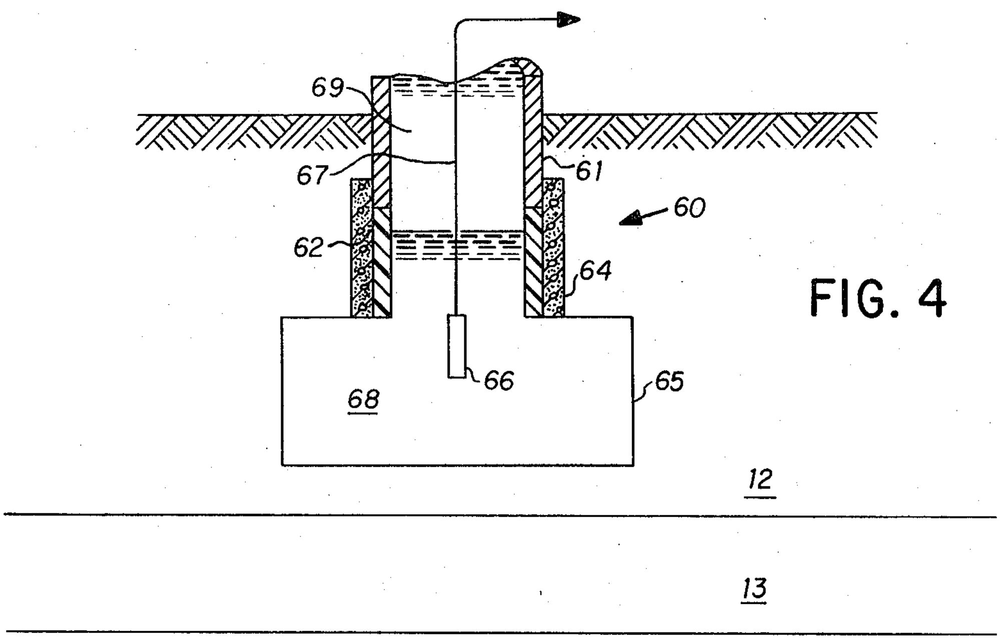

FIG. 4

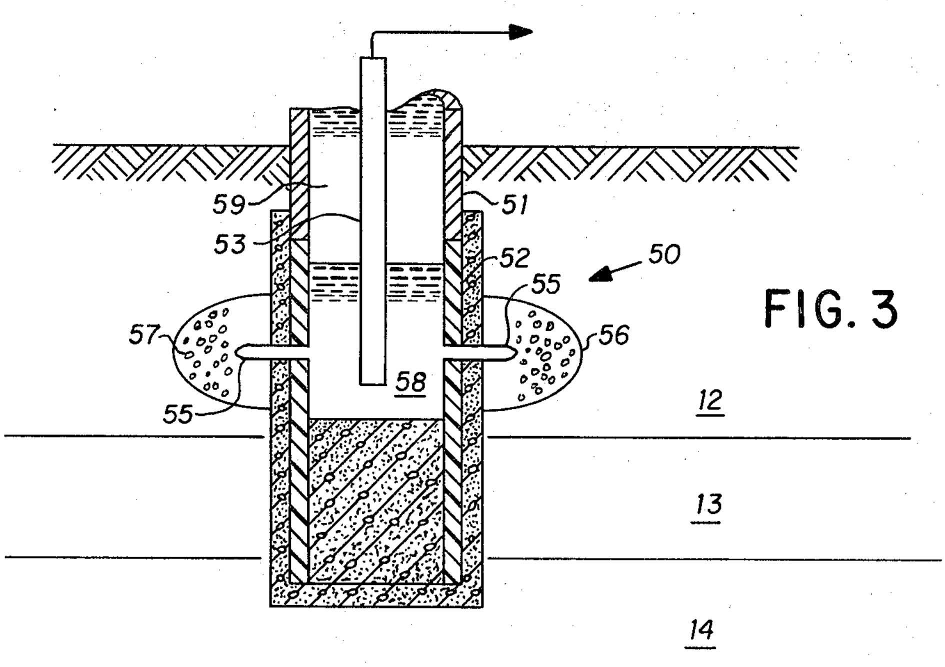

FIG. 3

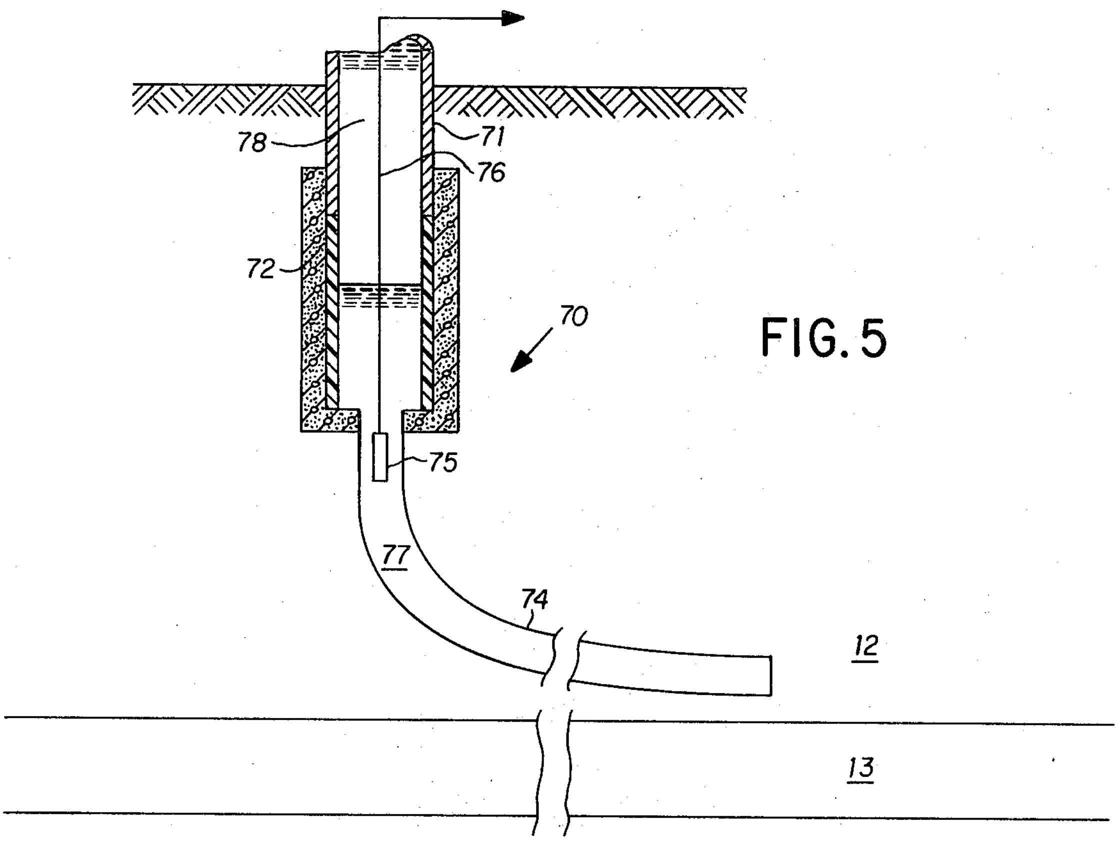
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FIG. 5

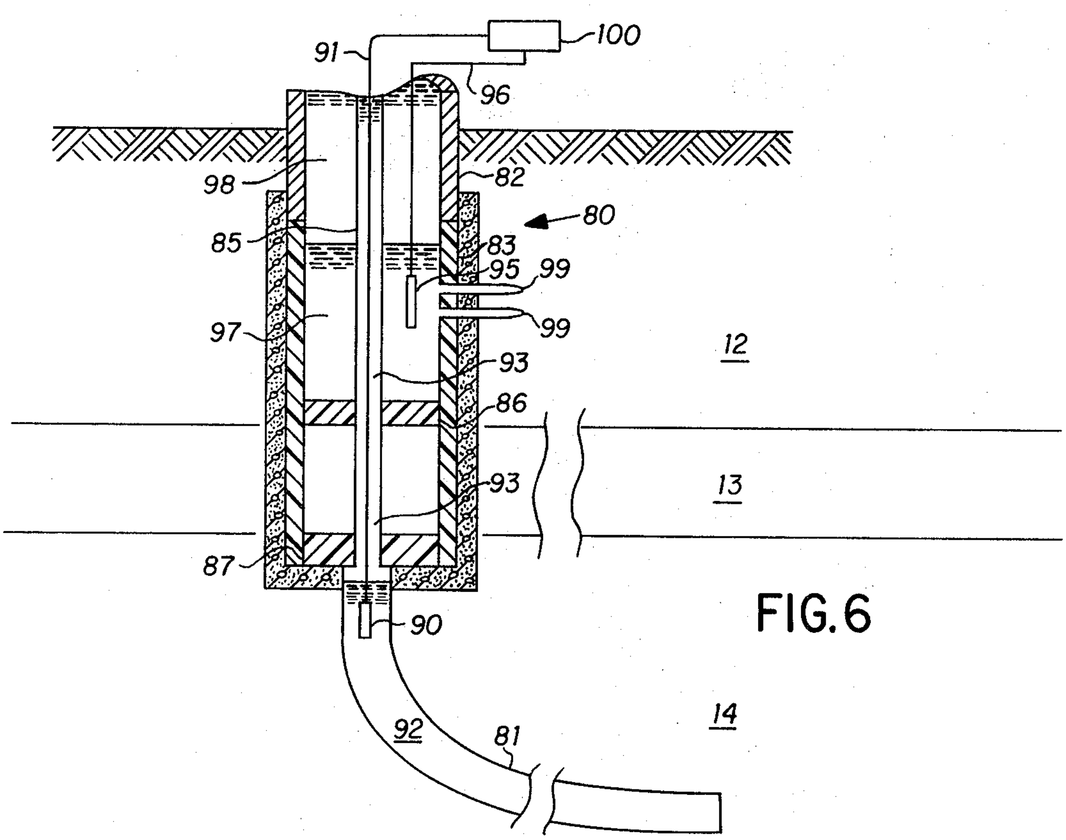
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FIG. 6

METHOD AND APPARATUS FOR ELECTRICAL HEATING OF HYDROCARBONACEOUS FORMATIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention is related generally to the application of electrical energy in the heating of subsurface hydrocarbonaceous formations including tar sands and other viscous oil bearing formations. More particularly, it relates to a method and apparatus to accomplish this purpose wherein an alternating current is applied in a closed-loop electrical system completed through the formation of interest, wherein reservoir water is the current carrier.

2. Description of the Prior Art

There is a considerable body of prior art relating to the general field of so-called electrothermic processes for raising the temperature of hydrocarbonaceous formations, all of which rely upon the electrical conductivity of the formation. Known techniques typically involve sinking a well into the formation having an electrode positioned near its bottom in electrical contact with the formation. The electrode is formed as part of an alternating current circuit extending through the wellbore from the surface, the circuit being completed through the formation. One such technique is proposed in the Oil & Gas Journal for December 1969, beginning at page 162. In a single well drilled through an oil bearing sand, two vertically separated electrodes are placed in contact with the formation. The electrodes are formed as part of an electric circuit which is completed by current flow through the sand between the electrodes. Current will travel through the connate water in the formation present in low percentage and create a temperature increase. However, it is conceded that the current flow will be greatest close to the wellbore in order to minimize the length of the current path between electrodes. Thus, heating of the formation will decrease with the distance from the wellbore.

Another application of electric current in heating of an oil reservoir is described in World Oil for May 1970, beginning at page 83. An electrode is formed at the base of an open hole in contact with the earth within the reservoir to be heated. The circuit includes steel tubing extending from the surface through the wellbore to the electrode, the tube being connected at the surface to an alternating current source which also has a ground connection. Current disperses into the earth from the electrode and returns to the surface through the overburden to complete the circuit. Again, a heated zone is produced in the vicinity of the electrode, the affected area being dependent upon the distance from the electrode center and the increase of formation resistivity with time in the area of the wellbore.

An example of a patented apparatus of this general character is disclosed in Gill, U.S. Pat. No. 3,642,066. Here the current path from a bottom electrode is through the formation of interest in the vicinity of the wellbore and then through a portion of the overburden to a section of conductive well casing extending downward from the surface. It is clear that effective heating is narrowly confined to the vicinity of the wellbore.

It is apparent, therefore, that the above techniques will not be effective to electrically heat a hydrocarbonaceous formation with substantial uniformity over any considerable range from the wellbore.

It has also been suggested in the art as typified by Crowson, U.S. Pat. No. 3,620,300, that it is possible to conduct a current through an oil bearing formation between electrodes each positioned in contact with the formation within adjacent wells. The effectiveness of this technique is predicated upon the assumption that the current path in the earth will be confined to the formation itself to be heated. However, it is well known that subterranean hydrocarbonaceous formations such as tar sands are frequently surrounded by layers of shale, limestone, or clay of considerably lower electrical resistivity than that of the tar sand itself. For example, tar sands typically have a resistivity of approximately 100 ohm-meters to about 5 ohm-meters or less for shale. This factor will adversely affect the electrical heating of such a formation by techniques such as Crowson's. Because of the higher conductivity of the surrounding layers, as soon as current passes into the tar sand from one electrode it will revert at least partically to the upper or lower layer of shale and remain within such layer until it reaches the vicinity of the opposite electrode, at which point it will then dip into the tar sand formation again. As a consequence, there will be a much higher degree of heating of the tar sand in the vicinity of the two electrodes and a lesser degree of heating in the central or intermediate portions of the tar sand.

SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide a method and apparatus for electrically heating a subterranean formation with substantial uniformity.

It is another object of this invention to provide a method and apparatus for electrically heating a subterranean hydrocarbonaceous formation which depends for its operation upon the differing electrical resistivity of the formation and the surrounding upper and lower layers.

These and other objects will become apparent from the descriptive matter set forth hereinafter particularly when taken in conjunction with the drawings.

In accordance with one aspect of this invention, a pair of wells are drilled from the surface at a preselected interval extending through a hydrocarbonaceous formation situated between and immediately adjacent an upper and a lower layer, each of significantly lower resistivity than that of the formation. A first electrode is positioned in one of the wells at a point above the formation and in electrical contact with the upper layer. A second electrode is positioned in the second wellbore below the formation and in electrical contact with the lower layer at that point. Conductive means are provided which extend from the surface within each wellbore to contact each electrode, and these conductive means are in turn connected at the surface to a source of alternating current voltage. A potential difference is thus established between the two electrodes causing a current to flow between the two electrodes through the formation. The current will traverse an indeterminate number of separate paths of substantially constant resistivity passing downward through the formation at successive points along the interval between the wells, each such path occupying a portion of the upper and lower layers.

Suitable means may be provided to confine the current paths from each electrode so that they proceed directly into the adjacent upper and lower layers respectively. Well casings may be provided having a plurality of perforations adjacent the position of the electrodes and communicating with the upper and lower layers respectively. Alternatively, the electrodes may be formed as part of portions of uncased borehole of enlarged diameter in order to increase the effective area heated by the flow of current.

Additionally, the method of this invention may be practiced by separating two electrodes by a suitable potential difference, positioning them respectively above and below a higher resistivity formation of interest within a single wellbore and in electrical contact with the upper and lower adjacent layers, and suitably isolating said electrodes from their surroundings such that current flows from one to the other through the formation along multiple paths whose resistivity remains substantially independent of the distance from the wellbore.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view, partly schematic and partly in section, illustrating one simplified embodiment of this invention,

FIG. 2 is a diagrammatic representation of typical current paths established through the formation of interest employing the method and apparatus of this invention,

FIG. 3 is a side elevational view, partly schematic and partly in section, illustrating a modified form of this invention,

FIG. 4 is a side elevational view, partly schematic and partly in section, illustrating another modified form of this invention,

FIG. 5 is a side elevational view, partly schematic and partly in section, illustrating still another modification of the apparatus of this invention, and

FIG. 6 is a side elevational view, partly schematic and partly in section, illustrating yet another modification of the apparatus of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there are illustrated two well boreholes **10** and **11** extending downward from the surface through the upper layer **12**, through the hydrocarbonaceous formation **13**, and terminating within the lower layer **14**. The holes **10** and **11** may typically be from 200 to 600 feet apart. Extending from the surface within well boreholes **10** and **11** are electrodes **16** and **17** which are positioned above and below the formation **13** and supported respectively by means of conductors **18** and **19**, such as wires of steel or copper, interconnected at the surface to a source of alternating current voltage **20**. The electrodes **16** and **17** may consist preferably of elongated steel bars or strips. If desired, the conductors **18** and **19** may alternatively consist of conductive tubing such as of steel, and electrodes **16** and **17** may then constitute terminal portions thereof.

The casing for the borehole **10** includes an upper conductive portion **22** terminating at a depth somewhat above the top of the electrode **16** and above the interface between upper layer **12** and the formation **13**. The conductive portion **22** may consist of conventional steel material or the like. The lower nonconductive portion **23** of the casing for borehole **10** extends adjacent to the bottom of the hole **10** and may be fabricated of fiberglass or other similar material. The void or cavity below the electrode **16** and borehole **10** may be conveniently filled with cement **24**, such as partially surrounds the casing as shown, or other insulating material. The volume immediately surrounding the electrode **16** is filled with an electrolyte **25** such as a sodium chloride solution. Finally, the borehole **10** above the level of the electrolyte **25** may be filled with insulating fluid **27** such as oil to insure a conductive barrier between electrode **16** and the conductive casing **22**.

In similar fashion, the casing for the borehole **11** comprises an upper conductive portion **30** extending downward from the surface to a depth terminating above the interface between the upper layer **12** and the hydrocarbonaceous formation **13**. The lower nonconductive portion **31** of the casing for the borehole **11** may extend adjacent the bottom of the hole **11** and contact the cement liner **32**. The material for these conductive and nonconductive portions **30** and **31** may, of course, be the same as that for the casing of borehole **10**. The void immediately surrounding the electrode **17** may be filled with electrolyte **33**, and the volume above the electrolyte **33** may be filled with an insulating fluid **34** such as oil.

A plurality of perforations **35** and **36** may be drilled through the respective casing portions **23** and **31** of wellbores **10** and **11** extending into the upper layer **12** and the lower layer **14** adjacent electrodes **16** and **17**. In this manner a good conductive path is established between these electrodes and the upper and lower layers **12** and **14** through the medium of electrolytes **25** and **33**. At the same time the nonconductive casing portions **23** and **31** together with the insulation **24** and **34** insure that there will be no conductive paths between electrodes **16** and **17** directly into the formation **13**. Nor for the same reason will there be any possibility of a good conductive path leading directly from either electrode through its respective borehole into the layer above or below, as the case may be, on the opposite side of the formation **13**, which would permit an electrode-to-electrode path completely bypassing the formation **13**.

Operation

In operation, when the alternating current source **20** is energized, a voltage gradient is established between electrodes **16** and **17** of predetermined magnitude. For example, this may conveniently be on the order of several thousand volts and up to 1,000 amperes. Responsive to this voltage gradient and as part of a closed-loop system incorporating the alternating current source **20**, the electrodes **16** and **17**, and the conductors **18** and **19**, alternating current will flow between the electrodes **16** and **17** through the earth. The paths followed will be from electrode **16** into the upper layer **12**, then intermediately through the formation **13**, and finally into the lower layer **14** to the electrode **17**. If the upper layer **12** and lower layer **14** have significantly lower resistivities than that of the formation **13**, which is the prevailing condition in certain locations, any of the current paths followed will tend to be substantially rectilinear. That is to say, the intermediate portion of the paths traversing the formation **13** will tend to be directed normal to the interfaces between the respective layers in order to minimize the length of this high resistivity portion.

With reference now to FIG. 2, a plurality of such current paths are illustrated, such as paths 40, 41, 42, 43, and 44. It is hypothesized that as soon as the system reaches a steady state condition, a plurality or infinite number of paths of this generally rectilinear shape will be formed, each including terminal portions such as, for example, portions 45 and 46 extending respectively within the upper layer 12 and the lower layer 14 and intermediate portion 47 extending through the formation 13 substantially at right angles to the interface between the respective strata. The low resistivity upper layer 12 and lower layer 14 may be compared roughly in this natural geologic formation to a pair of infinite high conductivity metallic conductors separated by one of lower conductivity. Since both edges of the conductors shortly stabilize at substantially equal potential, all current flow between them tends to be at right angles.

It may now be appreciated that the passage of current along this plurality or infinite number of current paths through the formation 13 will result in a substantial uniformity of heating thereof between the wellbores 10 and 11 and over a cross-sectional area dependent upon effective electrode radius, which is the result to be accomplished.

In order to enhance the effectiveness of this system and method, an alternate mode of constructing the apparatus may be adopted in accordance with FIG. 3. For purposes of discussion, this alternate embodiment is described only in conjunction with the borehole 10, but it will be understood that an equivalent modification may be introduced in construction of each of the wells and electrodes employed in the practice of this invention. With respect, therefore, to this alternate embodiment, a well borehole 50 may extend from the surface through the upper layer 12, the formation 13, and into the lower layer 14. The borehole 50 may be provided with an upper conductive casing portion 51 joining a nonconductive casing portion 52 extending between the upper layer 12 and the lower layer 14 adjacent the base of the borehole 50. A conductive tube 53 may be introduced within the borehole 50 from the surface and extended downward so that it terminates above the interface between upper layer 12 and the formation 13. Perforations 55 may be provided in the nonconductive casing portion 52 by known techniques to permit the creation of a hydraulic fracture 56 containing propping particles 57 effectively increasing the radial extent of the wellbore. The fracture 56 together with the surrounding volume of the voids within the borehole 50 may then be completely filled with electrolyte 58 so as to establish a good current path between conductors 53 and the upper layer 12. Finally, the space above the level of electrolyte 58 may be filled with insulating oil 59. The enlarged contact area between the cavity 56 and the upper layer 12 enables a heavier current to flow without increasing current density and temperature beyond tolerance for the electrolyte or the formation itself. A borehole (not shown) laterally adjacent to borehole 50 may also be provided with an effective electrode of enlarged radius corresponding to fracture 56 but situated in electrical contact with the lower layer 13. If these electrodes are interconnected at the surface to an alternating current source, current will pass through the formation 13 in the same manner as described above in connection with FIG. 1. The fracture 56 and its counterpart in the opposite wellbore may extend laterally 25 to 50 feet. Therefore, the current paths between electrodes will tend to lie in parallel planes over this distance. This will in turn provide greater uniformity of heating of the formation 13, not only between the electrodes, but also in a transverse direction.

A further modification of the apparatus of this invention is envisaged in FIG. 4 wherein a wellbore 60 extends from the surface terminating above the interface between the upper layer 12 and the hydrocarbonaceous formation 13. A portion of conductive casing 61 extends partially down the wellbore 60 and joins a portion of nonconductive casing 62 reaching the bottom of the cement liner 64. Below the casing 62, the wellbore 60 may be considerably enlarged in diameter in bottom portion 65 and left uncased. Electrode 66 is supported from the surface by a conductor 67 within electrolyte 68 which fills the enlarged wellbore portion 65 and extends upward within the nonconductive casing portion 62 to a point below its juncture with the conductive casing portion 61. Insulating oil 69 may fill the remaining space above electrolyte 68. Since the wellbore 60 terminates above the formation 13, all electrical paths from electrode 66 must include the upper formation 13, thus eliminating any chance of short-circuiting the formation 13. Obviously, the embodiment of FIG. 4 may be utilized with a second electrode (not shown) positioned in a second adjacent wellbore extending through the formation 13 and terminating at the bottom in a similarly enlarged uncased portion. Portion 65 of wellbore 60 provides a convenient means for enlarging the effective electrode interface with the upper layer 12. This decreases the current density and temperatures which accompany any given potential difference between electrodes employed in the practice of the method of this invention.

Yet another embodiment of the apparatus of this invention is illustrated in FIG. 5. In this modification a wellbore 70 extends vertically from within the surface of the upper layer 12 and is provided with an upper conductive casing portion 71 and a lower nonconductive casing portion 72. At the bottom of the casing portion 72, the bore 70 may be drilled by known techniques along a deviated curving path (obviously not shown to scale) to form a laterally extending section 74 substantially paralleling the upper boundary of the formation 13. An electrode 75 may be suspended from the surface within the wellbore 70 by means of conductor 76 connected at the surface to an alternating current source 20. Finally, a quantity of electrolyte 77 may fill the section 74 and a portion of the vertical part of the wellbore 70 sufficient to cover the electrode 75 and the space above electrolyte 77 filled with insulating oil 78. The effective contact area between electrode 75 and the upper layer 12 is determined by the length and diameter of the section 74. A second borehole (not shown) may be drilled through the formation 13 at a preselected interval and provided with a bottom deviated section similar to section 74, substantially paralleling the lower boundary of formation 13, both deviated sections being directed in the same sense transverse to a line between the vertical portions of the two boreholes. When current passes between the electrodes in two such boreholes in the manner provided in this invention, substantially linear current paths, as viewed from above, will be established over the full length of the horizontal section 74 and its counterpart in the opposite wellbore. In consequence, uniform electrical heating of the formation 13 can be extended over an area limited only by the length of the section 74. Obviously, this effect can be still further enhanced by providing each wellbore with additional deviated sections (not shown) angularly separated from section 74 and from each other.

As shown in the modification of FIG. 6, the method of this invention is not limited to the use of two spaced apart wellbores. In this embodiment a single wellbore 80 may be drilled through the layer 12 and formation 13 and preferably terminated in a deviated uncased section 81 extending laterally beneath the formation 13 and within the lower layer 14 substantially paralleling the interface with the formation 13. The upper conductive casing portion 82 joins a lower nonconductive casing portion 83 which extends to the bottom of the vertical portion of the borehole 80 as shown. A hollow tube 85, centralized within the bore 80 by means of the insulating packers 86 and 87, provides a channel for an electrode 90 supported by conductive means 91 below the packer 87 and within the electrolyte 92, which fills the horizontal section 81. The bore of the tube 85 above the electrode 90 is filled with a nonconductive oil 93. A second electrode 95 is supported between the centralized tube 85 and the nonconductive casing 83 by conductive means 96 interconnected at the surface along with conductive means 91 to an alternating current source 100. The electrode 95 is positioned at a height above the interface between the upper layer 12 and the formation 13. It is surrounded by suitable electrolyte 97 while the space thereabove is filled with insulating oil 98. Perforations 99 are provided through the casing 83 extending into the upper layer 12 to establish good electrical contact with such layer. If an alternating current potential difference is established between electrodes 90 and 95 by means of source 100, current will flow in accordance with the teachings of this invention through both upper and lower layers 12 and 14 and intermediately through the formation 13. Multiple current paths will be established each of which will be substantially normal to the interface between formation 13 and its adjoining layers. At any given distance from the wellbore 80, therefore, the resistance to current flow varies primarily in accordance with the length of low resistivity path traversed in the upper and lower layers 12 and 14. Furthermore, since the effective contact area for electrode 90 is determined by the length and dimensions of section 81, the electrical paths tend to remain substantially linear over th length of this section, thus increasing the area of uniform electrical heating of the formation which may be achieved with the single wellbore construction described herein.

From the foregoing, it can be seen that this invention provides a novel and unobvious method and apparatus for achieving substantially uniform heating of a subterranean hydrocarbonaceous formation such as a tar sand. The invention overcomes the nonuniformity which is inherent in prior art electrical heating methods and also provides a way of avoiding the nonuniformity resulting from prior art heating techniques involving fracturing and steam injection.

Although the invention has been described with a certain degree of particularlity, it is understood that the present disclosure has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the

spirit and scope of the invention as hereinafter claimed.

What is claimed is:

1. The method of electrically heating a subsurface formation situated between and immediately adjacent an upper and a lower layer each having a lower electrical resistivity than that of the formation comprising the steps of:

a. establishing a potential difference between a first and a second electrode means positioned respectively within the upper and lower layers and in electrical contact therewith and

b. causing an alternating current to pass between said electrode means responsive to said potential difference along a plurality of paths through said formation determined by the relative resistivities of said formation and said upper and lower layers.

2. The method of claim 1 wherein said subsurface formation is hydrocarbonaceous.

3. The method of claim 1 including the step of increasing the linearity of the current paths between said electrode means by extending the effective area of contact between said electrode means and said upper and lower layers substantially parallel to the upper and lower boundaries of the formation.

4. The method of claim 1 wherein said first and second electrode means are situated respectively within first and second boreholes spaced apart at a predetermined interval.

5. The method of claim 4 including the step of electrically isolating each of said electrode means within said boreholes such that each of said current paths between said electrode means must include the upper and lower layers and traverse the formation intermediately therebetween.

6. The method of claim 5 including providing casings for said boreholes having nonconductive portions extending above and below said formation.

7. The method of claim 6 including providing perforations in said nonconductive portions adjacent said electrode means communicating with said upper and lower layers respectively.

8. The method of claim 7 including partially filling the boreholes with electrolyte surrounding said electrode means and extending within said perforations.

9. The method of claim 1 including first and second spaced apart boreholes extending respectively within said upper and lower layers, said first and second boreholes being provided respectively with a first and a second deviated section extending in the same sense and substantially parallel to the respective upper and lower boundaries of said formation, said first and second electrode means being situated respectively within said first and second deviated sections in electrical contact with said upper and lower layers substantially over the interface between said upper and lower layers and said first and second deviated sections.

10. The method of claim 9 additionally including the step of extending said deviated sections of said first and second boreholes transversely to the direction between said boreholes.

11. The method of claim 1 including positioning said first and second electrode means within a single borehole.

12. The method of claim 11 including providing said borehole with a laterally extending deviated section substantially parallel to the lower boundary of said formation, said second electrode means being situated

within said deviated section in communication with said lower layer substantially over the interface between said lower layer and said deviated section.

13. Apparatus for electrically heating a subsurface hydrocarbonaceous formation situated between an upper and a lower adjacent layer each of lower electrical resistivity than that of said formation comprising:

a. first electrode means positioned in electrical contact with the upper layer;
b. second electrode means positioned in electrical contact with the lower layer;
c. first and second conductive means connected respectively to said first and second electrode means and extending to the surface; and
d. a source of alternating current voltage connected at the surface between said first and second conductive means adapted to produce an alternating current voltage gradient between said first and second electrode means whereby an alternating current is caused to flow between said first and second electrode means along a plurality of least resistance path through said formation.

14. Apparatus as in claim **13** including means for electrically isolating said first and second electrode means so that the available current paths between said electrodes each inclue the upper and lower layers and transverse the formation intermediately therebetween.

15. Apparatus as in claim **13** wherein said first and second electrode means are located respectively within first and second boreholes extending from the surface and spaced apart at a predetermined interval.

16. Apparatus as in claim **15** wherein said first and second boreholes are each provided with a deviated section extending in the same sense, substantially parallel to the respective upper and lower boundaries of said formation and transverse to the direction between said boreholes, and wherein said first and second electrode means are situated respectively within said first and second deviated sections in contact with said upper and lower layers respectively along the interface between said upper and lower layers and said respective first and second deviated sections.

17. Apparatus as in claim **15** including a casing within each of said boreholes, each of said casings comprising a conductive upper portion extending from the surface and a nonconductive lower portion joining the conductive portion and extending above and below the formation, separate fluid conductive means surrounding each of said electrode means respectively within said nonconductive portions, the remainder of said casings being filled with insulating material, and said nonconductive portions being provided with conductive paths therethrough adjacent said electrode means to permit electrical contact between said electrode means and said upper and lower layers, respectively, through said fluid conductive means.

18. Apparatus as in claim **15** wherein said nonconductive portions are provided with a plurality of perforations opposite said electrode means communicating with said upper and lower layers, respectively.

19. Apparatus as in claim **15** wherein said first and second electrode means are steel bars.

20. Apparatus as in claim **15** wherein each of said conductive means is a wire.

21. Apparatus as in claim **15** wherein each of said conductive means is a conductive tube.

22. Apparatus as in claim **13** wherein said first and second electrode means are confined within a single wellbore.

23. Apparatus as in claim **22** further comprising a casing within said wellbore, a tube centralized within said casing, said first electrode means being supported by said first conductive means between said centralized tube and said casing, said second conductive means extending through said centralized tube and supporting said second electrode means in axial alignment therewith, separate conductive fluid means surrounding said first and second electrode means respectively, means for establishing a contact area between said fluid means and said upper and lower layers, respectively, and means within the casing for insulating said first and second electrode means from each other and from the formation.

24. Apparatus as in claim **23** wherein said wellbore is provided with a deviated section extending laterally for a predetermined distance, said deviated section being completely filled with said fluid conductive means surrounding said second electrode means.

25. Apparatus as in claim **13** additionally comprising first and second spaced apart wellbores extending respectively within said upper and lower layers, a first and second plurality of angularly spaced deviated wellbore sections extending laterally from the vertical axis of said first and second wellbores respectively, a first and second quantity of fluid electrolyte substantially filling said first and second plurality of angularly spaced deviated wellbore sections and defining said first and second electrode means, said first and second quantities of fluid electrolyte being adapted to communicate with said upper and lower layers respectively along their interfaces with said first and second plurality of deviated wellbore sections.

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