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OIL RECOVERY BY IN SITU COMBUSTION

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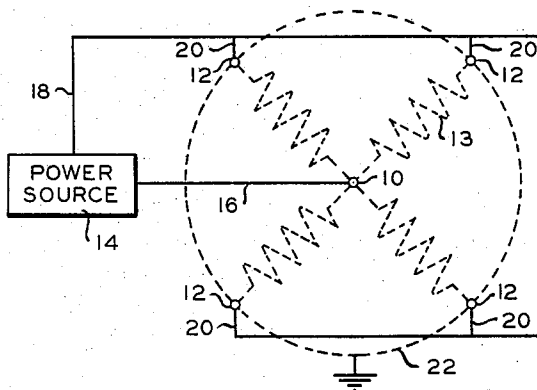


FIG. 1.

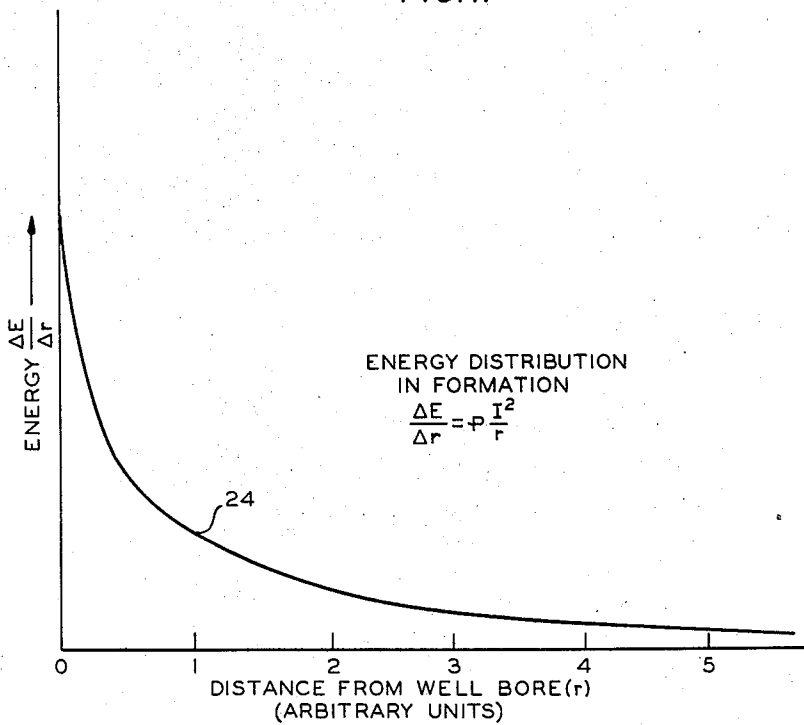


FIG. 2.

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OIL RECOVERY BY IN SITU COMBUSTION

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6 Claims. (Cl. 166—11)

This invention relates to a process for recovering oil from an oil-bearing formation by in situ combustion.

The recovery of oil from oil-bearing formations by in situ combustion is currently being emphasized as a production technique. The conventional method employed comprises initiating combustion of the oil adjacent a borehole in the formation by any suitable means and injecting air through the borehole into the formation so as to drive the resulting combustion zone or front radially and laterally outwardly from the borehole. A recent development in in situ combustion technique in the field of oil recovery is disclosed and claimed in the copending application of John W. Marx, Serial No. 526,388, filed August 4, 1955, and comprises establishing a combustion zone around a production well by conventional methods so as to provide a combustion zone and a heat reservoir of sufficient extent and temperature to permit cutting off the direct flow of air through the production well and injecting air into the formation through one or more spaced-apart wells from the production well so as to cause the air to flow to the combustion zone at the production well and support combustion therein so that the combustion front is advanced countercurrently to the flow of air toward the injection well or wells. This technique is designated "inverse air injection in situ combustion" as opposed to "direct" air injection through the well or borehole around which combustion is initiated.

Another recent development in recovery of oil by in situ combustion is disclosed in the copending application of J. C. Trantham and A. R. Schleicher, Serial No. 529,916, filed August 22, 1955, and comprises continuing the injection of air through one or more injection wells after the combustion front has been advanced, by inverse air injection, to the injection well or wells so as to reverse the movement of the combustion front and drive the same back through the formation to the production well around which combustion was originally initiated. In this technique, designated "thermal echo," the returning combustion front feeds on the residual carbon deposited in the formation during the inverse air injection phase of the process.

It has been found that in many oil-bearing formations the crude is of such high API gravity (and low carbon residue) that the hot gases from a combustion front initiated around an injection well drive the hydrocarbon materials substantially completely away from the area in front of the combustion front thereby leaving insufficient fuel to sustain combustion and the fire goes out. This renders it impossible to initiate combustion and build up a sufficient combustion zone and heat reservoir to permit reversing the direction of the flow of air to the combustion zone in order to establish inverse air injection to support and drive the combustion zone toward the surrounding injection wells and away from the well in which the combustion is originally initiated.

Hence it is an object of the invention to provide a process or method for initiating in situ combustion for supporting inverse air injection and recovery of oil in an

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oil reservoir or formation containing crude of high API gravity. Another object is to provide a method of oil recovery by in situ combustion from an oil-bearing formation which is incapable of supporting in situ combustion by direct air injection. A further object is to provide a method of initiating in situ combustion in an oil-bearing formation. Other objects of the invention will become apparent from a consideration of the accompanying disclosure.

The method of this invention comprises carbonizing the oil in an oil-bearing formation around a well or borehole therein and thereafter initiating combustion of the resulting carbonaceous coke deposit by any suitable conventional method to establish a combustion front moving radially away from the borehole. Where the specific gravity of the crude is relatively low, the combustion front may be advanced through the formation by simply continuing the injection of air or other oxygen-containing gas into the formation through the borehole around which the combustion has been initiated or by "inverse air injection" through injection wells spaced apart from and surrounding this borehole.

The invention has its greatest application in establishing in situ combustion in oil-bearing formations of such high API gravity that conventional in situ combustion technique is not operable in that the original combustion drives the highly volatile materials from the formation to such an extent that insufficient residual hydrocarbon material remains to maintain combustion in the combustion zone and, therefore, it disappears for lack of fuel. By carbonizing the oil around the injection borehole without injecting air into the same during the carbonization, the resulting coke deposit provides adequate fuel for maintaining the combustion and heating up the formation to provide a sufficient heat reservoir to permit establishment of in situ combustion by inverse air injection technique whereby air is injected through surrounding wells into the formation and travels to the combustion front to advance the same through the formation to the injection wells and radially away from the well around which combustion has been initiated.

Carbonization of the oil in the formation around the original injection borehole should extend into the formation several feet radially from the borehole. A distance of at least 3 or 4, and preferably 10 to 15 feet, is desirable. The preferred method of initiating combustion comprises injecting air through the borehole around which the carbonization has been effected while the coke laid down by the carbonization is in hot condition at a temperature sufficient to support combustion by mere contact with atmospheric air. In instances where the deposited coke and the adjacent formation are below combustion supporting temperature when air injection is commenced, the combustion process can readily be effected by introducing air to the formation at a temperature of at least 600° F. This may be accomplished by means of an electric heater in the well near or adjacent the formation. Of course, other heating devices, such as gas heaters, and chemical heating devices, such as squibs, are also effective in heating the formation and/or injected air to combustion supporting temperatures.

The carbonization is accomplished by using the ignition well as one electrode. Other electrodes in wells grouped around the ignition well are connected and used as the "outer" electrode. These "outer" electrodes are commonly connected to the other side of the power source. Thus, the current density (and therefore carbonization) is greatest around the ignition well. The heaviest coking takes place in this area, which is desirable. By this means the formation is not equally carburized or heated, giving a saving in both power and recoverable (non-coked) oil,

The system is essentially a non-linear electrical resistor.

A more complete understanding of the invention can be had by reference to the schematic drawing in which Figure 1 is a plan view showing one arrangement of apparatus around a production well and surrounding injection wells; and Figure 2 is a graph showing the relation of electrical energy converted to heat in the formation to distances from well bore with an arrangement such as that shown in Figure 1.

Referring to Figure 1, an electrode 10 is positioned in a centrally located well with reference to four surrounding wells, each having positioned therein an electrode 12. Electrode 10 is connected with one output terminal of a power source 14 by means of line 16 while electrodes 12 are each connected to the other output of the power source by means of line 18 and connectors 20. Numeral 13 designates the path of current between the inner and outer electrodes. The grounded circle 22 represents an ideal outer electrode comprising an infinite number of wells and electrodes 12 forming a complete ring.

Figure 2 shows that the energy dissipated is concentrated near the center well surrounding electrode 10 under the curve 24. The formula for the total energy dissipated in the formation is derived as follows:

$$E=KI^2R$$

$$\Delta E=KI^2\Delta R$$

$$dR=\phi\frac{dr}{r}$$

$$\Delta E=\rho\frac{\Delta r}{r}I^2$$

$$\frac{\Delta E}{\Delta r}=\rho\frac{I^2}{r}$$

$$E_t=\rho I^2 \log \frac{r_t}{r_w}$$

where ϕ is a constant of formation parameters (thickness, permeability, fluid content, etc.); I is the current in the system; R is the resistance of formation; K is a conversion constant; r is the distance from the center well 10 in Figure 1; E_t equals total energy dissipated in the formation; r_w equals radius of center well bore 10; and r_t equals the radius to outer electrode.

Figure 2 illustrates that the pattern of coke laydown in the formation by control of the current density pattern may be effected by positioning a number of electrodes in a pattern surrounding the well around which the carbonization is to be effected and combustion initiated. For example, if one electrode is surrounded by a ring electrode (wells surrounding the center well with electrodes therein connected together), then the highest current density is in the area immediately surrounding the center well and the coke forms in this area, first, and termination of the carbonization can be effected when the coke deposition extends outwardly from the center electrode a sufficient distance to permit establishment of in situ combustion and institution of the inverse air injection technique while sufficient hydrocarbon material, including coke, is still present in the combustion area surrounding the center well. After inverse air injection is established and the combustion front moves outwardly radially from the central well, the central well which was originally an injection well becomes a producing well since the entire flow of gases and liquids is from the surrounding injection wells to this producing well.

Once the apparatus shown in Figure 1 is set up with electrodes in each of the wells grounded in the adjacent formation, the operation to effect carbonization is simple. The power is turned on so that current passes through the formation between the central and the outer electrode and because of the higher current density in the formation surrounding well 10, carbonization is effected in this area and when sufficient carbonization and coke deposit has been produced, the current is cut-off and air is im-

mediately injected through well 10 while the formation is at combustion supporting temperature so that ignition of the coke is immediately initiated. In most instances before all of the coke is consumed, flow of air into the well 10 is terminated and air is injected through wells 12 so as to flow air to the established combustion front surrounding well 10 whereby the combustion front is advanced toward wells 12 with produced liquids and vapors passing out well 10 where they are recovered as produced hydrocarbon and treated in conventional manner including separation, refining, cracking, etc.

If the technique of the invention is applied to a formation containing oil of sufficiently low API gravity to support direct air injection as a means of advancing the combustion front through the formation to the outer wells, the injection of air is continued through well 10 so as to drive produced hydrocarbons, including vapor and liquid, to wells 12. In most formations, it will be found that direct air injection is applicable only to the establishment of a combustion front and heat reservoir after which inverse air injection is required to propagate the combustion front either because of the vaporization of most of the hydrocarbons just outside the combustion front (radially) or because the combustion heats up the liquid hydrocarbons reducing their viscosity and driving them further into the formation from the input well where they cool in contact with the formation and again become highly viscous thereby shutting off the flow of gas through the formation and terminating the combustion because of inability to supply the combustion front with air.

The following example is presented to illustrate the operation of the invention but is not to be construed as unnecessarily limiting the same. A number of samples of oil-bearing sands (Jantha and Deerfield sites) in the form of perm plugs 1" in diameter and of various lengths up to about 10" were tested by subjecting opposite ends to a potential difference of 0-10,000 volts and the following results were observed:

(1) In the voltage range of 0-5,000 the current rose approximately in accordance with Ohm's law as the voltage increased. A frying or sputtering sound occurred and considerable sparking took place over the surface of the sample.

(2) In the voltage range of 5,000-10,000 both current and voltage fluctuated as the electrical activity over the surface of the sample increased. Current sometimes increased without a corresponding increase in voltage. Some heating of the sample took place.

(3) The current suddenly increased to very large values and the voltage dropped to the range of 2000 to 5000 volts. Violent heating occurred with the production of smoke, and oil boiled out of the core.

(4) With prolonged heating, the smoke disappeared and the core became coke-like in appearance. The current remained high and relatively independent of the voltage.

In application of the process in an oil field voltages not substantially in excess of 10,000 volts are effective in producing carbonization of the oil around a borehole. One technique which enhances the effectiveness of the process comprises fluctuating or pulsating the voltage in the initial stages in order to assist in the breakdown of the hydrocarbon in the formation.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. A process for producing an oil-bearing formation containing crude oil of high A.P.I. gravity of insufficient carbon residue to permit driving a combustion front thru said formation which comprises electrically carbonizing oil in the formation around an injection borehole therein to form a coke deposit capable of supporting

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combustion and extending a distance from said borehole in the range of 3 to 15 feet; thereafter initiating combustion of the coke deposit by contacting said coke with oxygen-containing gas injected thru said injection borehole under combustion conditions to establish a combustion front therein; thereafter cutting off the flow of air through said injection borehole; feeding air to the combustion front from at least one borehole spaced apart from said injection borehole so as to move the combustion front countercurrently to the flow of air through said formation; and recovering produced hydrocarbon from said injection borehole.

2. A process for producing an oil-bearing formation containing crude oil of high A.P.I. gravity of insufficient carbon residue to permit driving a combustion front thru said formation which comprises passing electrical current between a plurality of connected electrodes in as many wells in said formation surrounding a first well and an electrode in said formation in said first well so as to carbonize at least a portion of the oil in said formation adjacent said first well and extending therefrom a distance in the range of 3 to 15 feet; injecting air into said first well under combustion conditions so as to initiate combustion of the resulting coke and establish a combustion front around said first well; thereafter cutting off the flow of air thru said first well and driving said combustion front through said formation by injecting air thru the surrounding well; and recovering hydrocarbon driven from said formation by said combustion.

3. The process of claim 2 wherein air injection through

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said first well is terminated after said combustion front has passed radially therefrom through a portion of the coked area and air injection through the surrounding wells is then established to feed said combustion front and move same countercurrently to the flow of air so as to drive produced hydrocarbon out said first well.

4. The process of claim 3 wherein the combustion front is driven to the surrounding wells and injection of air through said wells is continued so as to drive the combustion front back toward said first well.

5. The process of claim 2 wherein air injection is initiated while said coke is at a combustion-supporting temperature.

6. The process of claim 2 wherein hot air at a combustion supporting temperature is injected into the formation around said first well to initiate combustion of said coke.

References Cited in the file of this patent

UNITED STATES PATENTS

1,372,743	Gardner	Mar. 29, 1921
2,497,868	Dalin	Feb. 21, 1950
2,584,606	Meriam et al.	Feb. 5, 1952
2,642,943	Smith	June 23, 1953
2,685,930	Albaugh	Aug. 10, 1954
2,793,696	Morse	May 28, 1957
2,795,279	Sarapuu	June 11, 1957

OTHER REFERENCES

Mining Congress Journal, October 1949, page 57.