

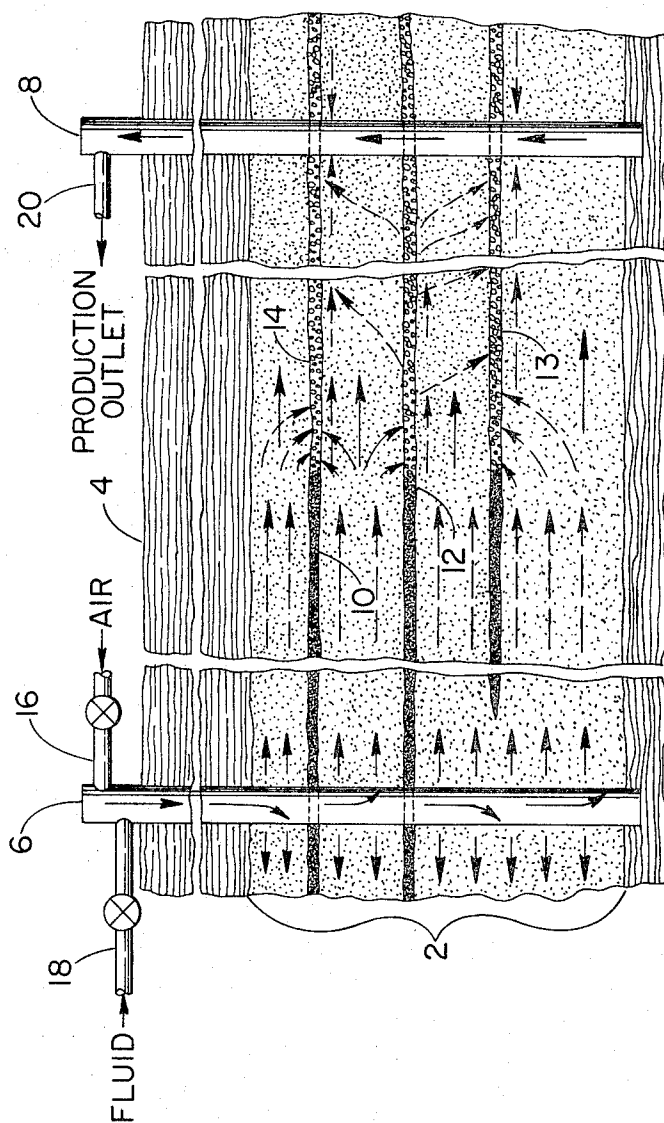
Jan. 30, 1968

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3,366,176

RECOVERY OF HIGH VISCOSITY OILS BY CONDUCTION HEATING

Filed April 28, 1966



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3,366,176

## RECOVERY OF HIGH VISCOSITY OILS BY CONDUCTION HEATING

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Filed Apr. 28, 1966, Ser. No. 545,981

9 Claims. (Cl. 166—11)

### ABSTRACT OF THE DISCLOSURE

Where steam flows through well-to-well fractures in an effort to distribute heat through the formation, the injected steam bypasses much of the oil. To remedy this, the well-to-well fracture is first created, and then the fracture is propped with a material that will not melt at steam injection temperature, but will melt at temperatures between steam injection and combustion temperatures; alternatively the material may be a readily oxidizable one. Then steam is injected until breakthrough occurs and/or oil producing rates decline. The proppant is then melted or oxidized, and steam injection or other thermal recovery method continued.

The present invention relates to the recovery of petroleum from an underground reservoir thereof by means of thermal methods. More particularly it is concerned with a novel process for the recovery of heavy viscous oils having an API gravity of not more than about 15° from preferably hard rock reservoirs wherein a conductive heating process of such oils is first effected to reduce the viscosity thereof and then followed by an appropriate fluid injection method.

Specifically, one or more fractures are created, for example, in a hard rock oil-bearing zone to connect injection and producing wells. The fracture is made in accordance with known techniques and with a liquid capable of carrying a propping agent stable at temperatures of the order of 550° to 650° F. but which melts, burns, or otherwise disintegrates in the presence or absence of oxygen at temperatures of from about 650° to about 1200° or 1300° F. The oil is then heated by injecting steam into the propped fracture until steam breakthrough at the producing well(s) or until a substantial reduction in oil producing rate is observed. Thereafter air is injected into the hot fracture(s) to increase the temperature therein causing the props to melt, burn, and/or oxidize, thereby permitting the fracture(s) to at least partially close or heal. Once this is done, steam injection or other fluid injection methods for producing the oil of reduced viscosity such as, for example, waterflooding or combustion, may be employed.

One of the principal disadvantages of any of the known direct drive thermal recovery processes is that they do not heat the oil ahead of the steam bank, or burning front, or in the area around the producing wells. The latter region is extremely important because it controls the oil producing rate. In these processes the oil must flow through the inter-well area while it is still cold and viscous. For example, to be operable, a direct thermal drive process such as in steam flooding, the flow capacity (expressed as  $kh/\mu_o$ , where  $k$  is permeability in millidarcys,  $h$  is thickness in feet, and  $\mu_o$  represents oil viscosity in centipoises) of the reservoir must be at least about 20. In those reservoirs where all other requirements are met but  $kh/\mu_o$  is less than about 20, ordinary steam flooding cannot be used. The importance of distributing heat throughout the reservoir and increasing the value of  $kh/\mu_o$  in a heavy oil reservoir arises from the fact that  $kh/\mu_o$  controls the oil producing rate and the pressure drop in the inter-well area.

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While conventional frontal drive steam flooding reduces the viscosity of the crude oil in the area immediately ahead of the high temperature front and thus provides good displacement efficiencies, the oil in the inter-well area and the critical region around the producing well is unaffected. As a result, the injection pressures can be excessive and production rates low.

It has been suggested that the oil can be produced by forming a well-to-well fracture, the injected steam then channels through the fracture, warming all of the oil by heat conduction. Following injection of a sufficient amount of steam to heat the pay zone, steam injection is shifted from the fracture to the pay so that oil of reduced viscosity can be displaced. There is evidence, however, that this procedure defeats the purpose of the fluid drive because the injected steam tends to flow through the fractured portion of the reservoir thus bypassing much of the oil, with oil production decreasing sharply at steam breakthrough.

In accordance with the process of my invention, these difficulties are overcome by forming the above-mentioned fractures with a liquid carrying a suitable propping agent ranging, for example, in size from about 10 to about 40 mesh and preferably from about 10 to about 20 mesh. This propping agent may be selected from a relatively wide group of materials which are stable and do not melt at temperatures up to about 550° to about 650° F., but which lose their compressive strength at temperatures of the order of from about 650° to about 1300° F. As examples of such materials there may be mentioned ground hard fruit stones, nutshells, synthetic or natural resins, etc. Other materials such as glass beads, aluminum, magnesium, and alloys of these and other metals, melting or losing their compressive strength within the above-mentioned temperature range, can also be used.

It is apparent that the operability of my process depends upon the actual existence of one or more fractures extending from the injection well to the producing wells. For this reason, the pattern employed for a given project generally should not cover an area of more than about 5 to 10 acres. With areas larger than this, the chances of being able to form connecting fractures are less than about 90 percent. Most heavy oil deposits for which the process of my invention is applicable are found at relatively shallow depths, i.e., less than 3,000 feet. At such depths it is usually much easier to form a horizontal fracture than at greater depths. The presence of heavy crude within the formation limits leak-off of fracturing liquid and thus makes it easier to extend the fracture. It is not necessary that the fracture be perfectly horizontal, but it is desirable that the fracture establish communication between the perforated zones of the injection and producing wells.

After one or more of such fractures have been formed connecting these wells, steam injection can be initiated. At first steam injection should be carried out at the full fracture or boiler capacity to realize the maximum rate of reservoir heating. Eventually, depending upon the injection rate, steam temperature and distance between wells, steam breakthrough occurs at the producing wells. Steam injection rate, steam temperature and distance between wells, however, in general, pressures greater than about 2000 p.s.i.a. should be avoided since the steam temperature is in excess of 635° F. and with many of the otherwise suitable propping agents, their compressive strength is materially reduced at temperatures above 635° F. Ordinary steam injection pressures of 800 to 1000 to 2000 p.s.i.a. are suitable. In any event, in order to achieve satisfactory conductive heating, heat is preferably supplied to the reservoir at the rate of about 10 to 15 million B.t.u. for each 24-hour period.

There are many benefits, of course, from conduction

heating of a heavy oil reservoir prior to subjecting the latter to any of several fluid injection processes. For example, the crude oil from the Nugget Formation in the Winkelman Dome Field, Wyoming, has a viscosity of about 900 cps. at the formation temperature of 85° F. If this formation is heated to 200° F. the viscosity of such oil is decreased to 33 cps. This reduction in viscosity brings about a 27-fold increase in  $kh/\mu_o$ . Productivity is considerably higher than that which is obtained at the normal formation temperature of 85° F. The rate of advance of the high temperature zone in a subsequent steam drive is also increased because of the decrease in the temperature difference between injected steam and the formation and because of the higher injectivities possible in the higher temperature formation. The rate of heat conduction from the fractures into the surrounding formation decreases with time. On the other hand, the percentage of steam entering the pay zone (as opposed to the fractures) at the injection well increases because of the reduction in viscosity of the oil in the pay zone. It is undesirable to waste heat by producing steam at the production wells. If the rate of steam condensation within the fracture and within the pay is not sufficient to prevent saturated steam from being produced, the steam injection rate should be decreased.

After breakthrough of steam into the producing well or the producing rate declines, air is injected into the formed fractures at a rate of from about 5,000 to about 50,000 cu. ft./hour. At the temperature prevailing in the fracture, e.g., 500° to 600° F., ignition is unnecessary, the injected air effecting a rapid oxidation of the oil generating more heat, ultimately causing the fracture props to melt, burn, or otherwise disintegrate. Essentially the same result can be obtained by the use of a lean fuel-gas-air mixture ignited in the fracture to destroy the propping agent. Alternatively, a mixture of hot gases, e.g., 500° to 600° F. steam and air, may be employed to bring about the necessary temperature in the fracture to overcome the compressive strength of the props. At the time the fracture closing or healing operation is begun, the fluid injection pressure is relatively low, e.g., 500 to 800 p.s.i. As the props in the vicinity of the injection well and out into the fracture melt, or are destroyed, the fluid injection pressure will be observed to increase. When such pressure has increased, for example, to roughly twice the original pressure, e.g., 1000 to 1500 p.s.i., the fracture or fractures can be considered to have healed or closed. In other words, healing of the fracture is indicated by a substantial increase in injection pressure. This fracture healing step generally takes place primarily within several feet from the injection well which fact is actually beneficial because as a result of this, the subsequently injected steam or other fluid is forced out into the rock matrix and after traveling through the pay zone for some distance, finds its way back into the unclosed fracture which still communicates with the producing well thus furnishing a relatively large drainage area into which the oil of decreased viscosity can flow. In place of steam injection after the fracture healing step, one may, if desired, employ other fluid injection methods such as, for example, hot or cold water flooding or injection of air to form a combustion front and producing the oil of reduced viscosity by ordinary in-place combustion.

In addition to the conditions already mentioned above, it should be pointed out that the pay zones to which the present process is applicable are preferably at least 20 feet in thickness in order to reduce the amount of heat lost to the cap and base rocks. Preferably, this should be a continuous sand since heat used to raise the temperature of nonpay sections is heat wasted. The process of the present invention is designed for those reservoirs where  $kh/\mu_o$  is low (less than 20 md. ft./cp.) solely because of high oil viscosity. Formation and crude properties should be such that this ratio can be made greater than 100 by heating the reservoir to 200° F. As previously indicated,

the present invention is directed to reservoirs containing tars or low API gravity crudes. These materials undergo the greatest decrease in viscosity when heated. To be beneficial the viscosity of the tar or oils should preferably undergo at least a 20-fold decrease when heated from reservoir temperature to about 200° F. This magnitude of viscosity reduction can be achieved with most crudes of gravity less than 15° API. Accordingly, the expression "high viscosity oil" as used in the present description and claims is intended to mean an oil or tar having a gravity of less than about 15° API. A high initial oil content is necessary to insure an economical process. The reservoir oil content should be greater than 780 barrels/acre foot.

The method of my invention will be further illustrated by reference to the accompanying drawing wherein portions of a heavy oil (12° API) bearing zone 2 is shown in vertical cross section. Oil bearing zone or formation 2 has an initial oil content of about 900 barrels per acre foot and is at a depth of about 1500 feet. From the earth's surface 4, at least two wells penetrate zone 2 at a suitable spacing, well 6 being equipped as an injection well and well 8 equipped as a producing well. These wells are shown only diagrammatically; however, it will be understood that the equipment not shown in detail may be any of that conventionally employed and connected in the ordinary manner, both wells having one or more strings of casing or tubing suitably cemented or supported in place, well 6 being connected to a conventional supply of oxygen or air under pressure flowing through valved line 16 and having a valved line 18 through which steam or other suitable fluid may be introduced. Well 8 is connected to apparatus for separating gas and liquid and for storing the recovered liquids. Since all of this equipment may be entirely conventional and no particular types are required for this invention, no detailed showing is considered necessary.

Before steam injection is initiated, one or more horizontal fractures are created in the formation between wells 6 and 8. These fractures may be started in and extended from wells 6 and 8 as shown by fractures 10 and 12. Formation of these fractures can be accomplished as desired by means and procedures now well known in the hydraulic fracturing art and as no special adaptation of these processes is involved in this invention, further detailed description is considered unnecessary.

With the fractures in zone 2 thus formed, they are held open by means of nutshells as the propping agent 14, 600° F. steam is injected at a pressure of about 1500 p.s.i., at a rate of about 20,000 lbs./hour. As this process continues, heat travels into formation 2 above and below fractures 10 and 12 and by the time steam breaks through into producing well 8, a major portion of the oil in the inter-well area has been heated to about 200° F. Next air is injected through valved line 16 into fractures 10 and 12 via well 6 at a rate of about 10,000 cu. ft./hour and at a pressure of about 800 p.s.i. At the temperature conditions prevailing in the fractures, i.e., about 600° F., additional heat is generated thereby initiating combustion of the hot oil. Such temperatures are generally in the neighborhood of about 1000° F. and cause the nutshell props to disintegrate wherever the temperature level approaches this figure. Such action in turn results in the at least partial closing of fractures 10 and 12. The darkened portion shown in the drawings of these fractures extend for a distance of several feet from injection well 6 and represent burned or disintegrated props that have lost their compressive strength, causing that segment of the fracture to close. The occurrence of this condition in fractures 10 and 12 is observed by a relatively rapid pressure build up to a value frequently as much as twice the original injection pressure. It should also be pointed out that it is contemplated as lying within the scope of my invention to burn, melt, or otherwise destroy the entire supply of propping agent in the fractures, causing the

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latter to effect a substantially complete healing thereof throughout the inter-well area.

Once fracture healing has occurred to the extent desired, steam or other appropriate fluid is then injected into formation 2 through valved line 18 and input well 6. The closed or healed fractures 10 and 12 thus force the injected fluid to take the path indicated by the arrows, thereby propelling oil of decreased viscosity into producing well 8 via the partially open fractures as well as through formation 2 and eventually out of the system through flow line 20.

It will be apparent from the foregoing description that I have provided a novel method for recovering tars and high viscosity oils heretofore considered essentially unrecoverable by conventional fluid injection methods. Thus by conduction heating through propped inter-well fractures, followed by closing said fractures, and thereafter injecting a suitable fluid to drive the hot oil to the producing well, I am able to effect oil recovery over a shorter flood life at lower injection pressures, higher producing rates, and with decreased heat losses. Also, while I have stressed in the present description that the fractures should be formed so that they extend continuously from one well to the other, the advantages of my invention may likewise be realized from fractures that are not necessarily continuous but which overlap and are a relatively short distance away from one another. Accordingly, the expression "inter-well fracture" as used in the description and claims is intended to refer either to continuous well-to-well or to overlapping fractures.

I claim:

1. In a method for recovering high viscosity oil from an underground deposit thereof penetrated by an injection well and a producing well,

the improvement which comprises first forming at least one inter-well fracture in said deposit bringing said wells into communication with one another, depositing a propping agent in said fracture, said agent having adequate compressive strength at temperatures up to about 650° F. to hold said fracture open, thereafter injecting steam into said fracture at a temperature below about 650° F. and below the temperature at which the specific propping agent employed loses its compressive strength whereby heat

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is transferred by conduction to the oil above and below said fracture and between said walls thereby substantially reducing the viscosity of said oil, next increasing the temperature in said fracture to a level sufficiently high to substantially destroy the compressive strength of at least a portion of said propping agent causing at least a segment of said fracture to close,

thereafter subjecting the resulting heated deposit to a fluid injection secondary recovery method, and recovering oil of reduced viscosity from said producing well.

2. The method of claim 1 wherein the temperature in said fracture is increased by injecting an oxygen-containing gas therein.

3. The method of claim 2 wherein said oxygen-containing gas is a mixture of steam and air.

4. The method of claim 1 wherein the temperature in said fracture is increased by burning a lean fuel gas-air mixture therein.

5. The method of claim 1 in which the propping agent employed is in the form of granular nutshells.

6. The method of claim 1 wherein steam is injected into said fracture until steam breakthrough into said producing well is obtained.

7. The method of claim 1 wherein said resulting heated deposit is subjected to a steam flooding operation.

8. The method of claim 1 wherein said resulting heated deposit is subjected to a waterflooding operation.

9. The method of claim 1 wherein said resulting heated deposit is subjected to an underground combustion operation.

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**UNITED STATES PATENT OFFICE**  
**CERTIFICATE OF CORRECTION**

Patent No. 3,366,176

January 30, 1968

David R. Parrish

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 60, strike out "jection rate, steam temperature and distance between wells." and insert instead -- injection may be effected over a wide range of conditions, --; column 6, line 2, for "walls" read -- wells --.

Signed and sealed this 1st day of April 1969.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

EDWARD J. BRENNER

Commissioner of Patents