

1

2

3,233,671 RECOVERY OF HEAVY CRUDE OILS BY IN SITU COMBUSTION

Alfred Chatenever, Tulsa, Okla., assignor to Sinclair Research, Inc., Wilmington, Del., a corporation of Delaware

No Drawing. Filed Dec. 18, 1962, Ser. No. 245,425
3 Claims. (Cl. 166—11)

This invention relates to a process for the recovery of oil from underground mineral oil-bearing formations by thermal means. More particularly, it relates to an oil recovery process wherein fuel deposition within the formation is adjusted so that where a relatively low gravity crude is in place, the amount of gas required to propagate an effective combustion front is substantially reduced, and where a relatively high gravity crude is in place, adequate fuel is provided to propagate an effective combustion front which would not otherwise be maintained.

It has previously been proposed to produce oil by the use of underground combustion. In one method a part of the oil or other combustibles within the formation is ignited by suitable thermal means to establish a heat wave or a combustion zone in the vicinity of one or more input wells. This heat wave is then moved, radially or otherwise, to other points in the formation by the injection of a gas (such as air), containing free oxygen, a mixture of such an oxygen-containing gas and an inert gas, a mixture of such an oxygen-containing gas and fuel, etc. As the combustion front moves outward from the injection well, the combustion gases, oil, and distillation products migrate in front of the combustion zone to an output well or wells, from which output well or wells these fluids are removed and thereafter treated if necessary, for recovery of the desired valuable constituents. The heated fluids migrating in front of the combustion zone strip the oil-bearing sand of the greater portion of oil. The oil remaining is cracked to form a carbonaceous hydrocarbon deposit. Also, as the combustion front moves outward connate water is vaporized and then condensed at a point further out in the formation where temperatures are lower. Additional water, which is a product of combustion, is also condensed in this area. The water thus exists in the form of a bank ahead of the heat wave and is instrumental in producing crude oil by displacement. Again, the crude oil which is not displaced by the water remains behind for recovery by the heat wave or to be converted to a carbonaceous material.

The carbonaceous material deposited in the formation is essentially a fuel for the combustion front, and before the front can advance through any given portion of the formation it is necessary to burn-off substantially all the carbonaceous deposit in that region. One of the most important economic factors in thermal recovery processes is the quantity of oxygen-containing gas, such as air, necessary to move the combustion front through a given volume of reservoir. This quantity of air depends in turn to a great extent on the quantity of the carbonaceous material which must be consumed before the combustion front can advance. The greater the quantity of residual carbonaceous material left in the formation subject to the combustion wave, the greater the quantity of oxygen-containing gas that must be supplied under pressure to the input wells to propagate the underground heat wave or combustion zone towards the output wells and the greater the quantity of oil consumed in the combustion. Generally, it has been found that lighter oils present in the formation leave fuels of such characteristics that it becomes difficult, if not impossible, to maintain combustion. The heavier oils leave a deposit of such a nature that the amounts of gas required to consume it become

prohibitive in cost. This cost is reflected for instance in compression costs for air and costs of oil consumed in the combustion, and such costs are a significant factor in the economic feasibility of the process.

It has now been discovered that in underground formations bearing oils that have undesirable combustion wave propagation properties, advantages such as a reduction in gas compression costs and an increase in oil-in-place recovery can be effected by altering the fuel-depositing characteristics of a thermal recovery process. These characteristics can advantageously be altered by injecting into the oil-bearing formation a bank of fluid with desirable fuel-depositing characteristics before starting the combustion wave. This fluid may be a residual mineral oil, for instance, crude petroleum oils, processed residual oils resulting from crude oil distillation processes or combinations of such oils having a significant portion which is not distilled under conditions of the in situ combustion. This method is applicable to formations containing petroleum crude oil deposits that are relatively heavy or relatively light or have other undesirable thermal properties, e.g., crude oils of 8 to 25 or 42 to 60° API gravity. The introduced fluid is injected in the input well and will move the natural crude oil deposit which does not have acceptable thermal properties in front of it, away from the injection well and through the formation. The oil-in-place is moved in a miscible displacement by the injected bank; consequently, the combustion front which moves the injected bank uses the fuel that is left by the injected fluid rather than that from the oil-in-place which would be undesirable. Thus, the combustion zone or heat wave is propagated through the formation, moving the injected bank before it, and this in turn displaces the oil-in-place before it. The process is continued until the natural petroleum crude oil and the unburned portion, if any, of the injected fluid is recovered at the output well or wells. Thus, as a result of the process of the present invention, a fluid with more desirable combustion properties replaces the oil-in-place, i.e., the natural petroleum crude oil, laying down a more suitable fuel. The instant invention thereby makes feasible thermal recovery operations in formations which are otherwise unsuitable because they provide too little fuel to maintain a combustion wave, or too much fuel which would make the cost of recovery prohibitive, or have other unsuitable properties. The in situ combustion process of the present invention can be any of the forward wave type where free oxygen-containing gas, combustion wave, oil-in-place, and a water bank are transported from an input towards an output well, for instance, as in U.S. Patents Nos. 2,642,934, 2,804,146, 2,793,697, 2,670,047, 2,874,777 hereby incorporated by reference.

The injected fluid with desirable fuel depositing characteristics employed in the present invention may be a residual oil which has an API gravity of 30 to 40°, ASTM D287-55. Frequently such oils exhibit a viscosity, cp., at reservoir temperatures (ASTM D445-60) of .5-8 and will leave or deposit a residual carbonaceous material of 15 to 22% of the oil when cracked at 900° F. under the conditions of the combustion process. The selection of a particular oil in any situation will depend on the various conditions and circumstances of the operation. The amount of fluid with desirable fuel-depositing characteristics provided or maintained may vary depending upon the formation, the oil-in-place, and the particular fluid employed; but typically it should be about 7 to 30, and preferably, about 15 to 25 percent of the pore volume occupied by the natural petroleum oil in the area to be swept by the combustion. This amount is that sufficient to maintain a miscible bank and deposit

fuel for the combustion to support the heat wave for a substantial distance between the input and output wells, preferably essentially the entire distance, with minimal consumption of oil and minimal amounts of oxygen-containing gas which are required to move the heat wave through the formation. The pore volume may easily be determined by the usual geological observation of test bores and core analysis.

In the preferred method of practicing this invention the oil-miscible fluid with desirable fuel-depositing characteristics is injected into the bore of an input well. A burner of the type, for instance, described in U.S. Patent No. 2,668,592 to John J. Piros and Oliver F. Campbell is then installed in the input well at formation level and ignited. A hydrocarbon fuel, conveniently natural gas, is burned with an oxygen-containing gas such as air at high temperature within the hole to effect ignition in the the oil-bearing formation. Usually, the fuel-air mixture is proportioned to provide a temperature within the range of about 700 to 1500° F. A sufficient period of preheating is provided to heat a substantial portion of the rock formation surrounding the well bore to a temperature above the ignition temperature for hydrocarbons in the formation, i.e., above about 450–500° F. to about 1500° F. or more. After the oil-bearing stratum around the well bore for a radius of several feet has been heated to a high temperature preferably about 1000° F. the combustion in the well bore is terminated. The heated zone is now moved into the formation, for instance, by injecting unheated, noncombustible gas such as combustion gases, air or air-containing an amount of fuel gas below the explosive limit. Air and fuel gas may be injected alternately in a manner preventing burning within the well bore or fuel gas containing an oxygen content below the rich explosive limit may be used for movement of the heated zone into the formation. The gases enter the well bore cold and pick up preheat from the rock face. By transfer of heat outwardly through the rock the heated zone is moved away from the well bore. Now a heat wave is established which can be propagated through the formation. An oxygen-containing gas drive is then employed to propagate the heat wave. Advantageously air is employed at as high an input rate as practicable taking into account the permeability of the rock, power requirements for compression and pressure limitations. The input rate and partial pressure of oxygen are maintained in any event high enough to insure combustion of the fuel deposited by the injected bank of oil-miscible fluid as the oil-in-place is displaced and moved out into the formation before the advancing oil-miscible bank and heat wave. Thus, regardless of the nature of oil-in-place, i.e. whether it is a heavy viscous hydrocarbon which would deposit too much fuel in the formation or whether it is a light hydrocarbon and would, therefore, leave too little fuel for the combustion front, the instant invention makes feasible its efficient recovery by depositing a suitable fuel in the formation so that the gas required to maintain an effective combustion front is utilized most efficaciously.

The following example is included to further illustrate the invention. In a 2½ acre field where the wells are arranged in an inverted "5-spot" and wherein the oil-bearing formation has a sand thickness of 10 feet, a porosity of 20 percent, a water saturation of 25 percent and containing about 800 barrels of oil per acre foot, said oil being characterized by having a viscosity of about 80 cp. at 100° F. and about 19° API gravity, the following procedure can be observed:

5,430 barrels of a crude petroleum oil with desirable

fuel-depositing characteristics comprising a crude oil having the following approximate properties:

Gravity ° API (ASTM D287-55) -----	38
Flash ° F. (ASTM D92-57) -----	375
5 Viscosity at 100° F., cp. (ASTM D445-60) -----	4

are injected into the input well. A burner is installed in the input well at the formation level and ignited. A hydrocarbon fuel is burned with air within the input well, the fuel-air mixture being proportioned to establish a combustion zone having a peak temperature of about 1000° F. The mixture is fed to the formation at a rate of about 1000 cubic feet (160° F. and 14.4 p.s.i.a.) per hour and generally comprises about 3 percent natural gas and 97 percent air. The combustion wave is then propagated through the 2½ acres to the producing wells by injecting air at a rate of about 1000 cubic feet (160° F. and 14.4 p.s.i.a.) per hour.

At the time of arrival of the water bank at the producing well the petroleum crude oil addition lowers the quantity of oxygen-containing gas required to propagate the combustion front through the formation by about 50 percent as compared with procedures where no crude petroleum oil is injected to deposit a more desirable fuel for combustion within the formation. The decrease is calculated by comparing the 20MM c.f. (million cubic feet at 60° F. and 14.4 p.s.i.a.) per acre foot of air usually required to propagate the combustion front in this type of formation to the 10MM c.f. per acre foot of air employed when the injected fluid with desirable fuel depositing characteristics is used. Further economies are effected due to the consumption of about 150 bbl. of oil per acre foot with the injected fluid compared with about 400 bbl. of oil per acre foot without the injected fluid.

I claim:

1. In the recovery of oil from an oil-bearing underground formation containing petroleum crude oil having an API gravity in the range of 8 to 25, wherein combustion is established within the formation, and an oxygen-containing propagating gas is injected into the formation from an input well to propagate said combustion toward an output well, the step which comprises injecting in the formation prior to the initiation of said combustion and in contact with said petroleum crude oil which it displaces, a fuel-depositing residual mineral oil of 30 to 40° API gravity in an amount equal to about 7 to 30 percent of the pore volume occupied by the petroleum oil in the area to be swept by the combustion to maintain a miscible bank between said crude oil and the combustion zone and deposit fuel for said combustion to support the heat wave and move the heat wave through the formation.

2. The method of claim 1 wherein the amount of said fuel-depositing residual mineral oil introduced is about 15 to 25 percent of the pore volume occupied by the petroleum oil in the area to be swept by the combustion.

3. The method of claim 2 wherein said fuel-depositing residual mineral oil is a crude petroleum oil.

References Cited by the Examiner

UNITED STATES PATENTS

2,793,697	5/1957	Simm -----	166—39
2,796,132	6/1957	Bruce -----	166—39
2,906,340	9/1959	Herzog -----	166—39
2,924,276	2/1960	Heilman -----	166—11
2,954,218	9/1960	Dew et al. -----	166—39 X

CHARLES E. O'CONNELL, *Primary Examiner*.

BENJAMIN HERSH, *Examiner*.