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PETROLEUM PRODUCTION PROCESS

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This invention relates to the so-called secondary recovery of oil from partially depleted oil-bearing formations, and particularly is concerned with an improved method of washing out the formation by injection of a combined liquefied hydrocarbon and water drive.

One of the extraordinary things about the feared potential shortage of oil is that several billions of barrels of oil remain in fully explored and worked oil fields even after the best efforts of petroleum production engineers have been devoted to producing them for many years. For example, the Bureau of Mines has estimated that about five and half billion barrels of Pennsylvania grade crude oil remain in the known Appalachian fields, but are non-recoverable by present recovery means.

Of course, one of the reasons for this anomalous situation is the fact that recovery of crude oil requires the expenditure of energy. Where high reservoir pressures combined with ideal natural water drive and conservative production methods obtain, recoveries as high as 70 to 80 per cent are possible. In general, however, it is a matter of common knowledge that primary production, including pumping and vacuum methods where applied, rarely exceeds one-third of the total oil content, and in the case of low pressure fields, such as the Nowata field of the Bartlesville sand more often averages only about 15 to 20 per cent. The application of external energy to implement crude oil recovery is primarily limited, of course, by the market price. However, re-pressuring with gas and water-flooding have been applied as so-called secondary recovery methods profitably in many fields to increase recoveries by perhaps another 20 to 30 per cent. We have now discovered an improved method of secondary recovery that obtains much higher percentage recoveries, and, where geological and lithological circumstances are favorable, permits nearly complete recovery of the oil contained within the porous formation.

Our new method is based upon the principle of washing the oil-bearing formation with a material possessing a relatively high solubility for crude oil so that the oil-connate water-sand equilibrium is displaced by solution of the crude oil. A light liquefiable hydrocarbon or mixture of liquefiable hydrocarbons is most useful for this purpose. Access is had to the formation as by any of the systems of input and outlet wells used in conventional secondary recovery. The light hydrocarbon is introduced to the formation through the input well in the liquefied state, and advantageously, of course, back pressure is main-

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tained upon surrounding outlet wells. After sufficient liquefied hydrocarbon has been introduced to saturate the formation immediately surrounding the input well, water is pumped into the input well in order to drive the liquefied wash hydrocarbon towards the outlet well or wells. Oil and gas are recovered from the outlet wells by releasing the pressure. Advantageously, a vacuum is applied by pumping, and the hydrocarbon used as wash liquid is recovered from the crude oil by fractionation.

We believe that our new method of secondary recovery produces greatly increased recoveries of crude oil because it positively displaces the oil-connate water-sand equilibrium. For example, we have found in laboratory tests that a liquefied hydrocarbon, forced through a sample of porous, partially depleted oil sand removes upwards of about 60 per cent of the total oil content in a single pass, while a light hydrocarbon gas field drive recovers only about 15 to 25 per cent of the oil content by pressure purging. According to our method the layer of liquefied hydrocarbon apparently washes out and dissolves the residual oil and the water serves to convey the wash, oil-bearing liquid layer through the formation to the outlet wells. The recovery of oil trapped or retained by adsorptive forces, together with connate water, in the pores and interstitial spaces of the sand is greatly increased. As wash liquid, propane, butane, or a layer of lower boiling naphtha, such as pentanes, hexanes, and the like may be used. These hydrocarbons are water insoluble, but are readily liquefied, and may be readily recovered with dissolved oil by releasing the pressure or pumping a vacuum on the formation, so that the wash liquid vaporizes from the interstices and separates from the water.

Advantageously, the formation is scrubbed more than once with the liquefied hydrocarbon. Thus, the formation is ordinarily subjected to the combined liquefied hydrocarbon and water drive by pushing a layer of liquid propane, for example, through the formation from an input well to an outlet well by means of a water drive. The propane-oil layer is recovered at the outlet well and the propane separated from the oil and pumped back into the flooded formation at the input well. The second injection of propane is then pushed through the formation by repeated pumping of water into the input well. The drive may be continued through additional cycles if desired.

Our new method thus may be applied to existing fields which have been subjected to conventional secondary recovery by water drive. For

example, in the case of certain areas of the Nowata field of the Bartlesville sand, the original oil content was 17,750 barrels per acre, and the primary oil recovery 2,440 barrels, with vacuum and pressuring yielding another 3,981 barrels. Conventional water flooding yields approximately 3,764 barrels more, which leaves a residual oil content of 6,858 barrels per acre, amounting to 42 to 43 per cent of the original oil content, as non-recoverable oil by known methods of secondary recovery. Again the method involves injection of a slug of liquefied propane or butane, for example, at the input well followed by water pumping to drive the hydrocarbon layer to the outlet wells.

Recovery of the hydrocarbons, that is wash liquid and oil, from the oil sand may be improved by the addition of surface-active agents; e. g., alkalies, alkaline salts, acids, or acidic salts, to the water used in the drive. It is advisable to select the particular agent on the basis of a trial conducted with cores taken from the formation in order to avoid emulsification difficulties. Obviously, surface-active agents having good wetting and penetrating action without appreciable oil emulsifying character are preferred.

Although our new method may utilize existing patterns of input and outlet wells in fields where conventional secondary recovery methods have been practiced, better results will be obtained by shortening the spacing between input and outlet wells. The advancing liquefied hydrocarbon layer material becomes richer and richer in oil content as it progresses through the formation and, therefore, progressively loses capacity as a solvent for the residual oil. Hence, it is desirable to operate so as to force the liquefied hydrocarbon; e. g. propane, through a length of oil sand limited, for example, to that containing residual oil which is soluble in propane in an amount approximating four or five times the volume of the propane employed. The use of successive cycles, however, permits considerable flexibility in this respect.

One or more outlet wells may be used for recovering oil and gas produced by our method, but as a practical matter several outlet wells as in the well known five spot or nine spot patterns should be used. Advantage may profitably be taken of known methods of well packing and blocking to control channeling which tends to reduce the recovery efficiency.

The principles underlying our invention will be illustrated in the following example, which obviously, however, is not intended to be limiting with respect to field procedure or operating conditions. The illustration describes a single pass, but recoveries are significantly raised by repeating the cycle.

Example.—A one-inch length of $\frac{3}{4}$ " oil-sand core taken from the Nowata field in Oklahoma, was cemented inside a two-inch length of $\frac{3}{4}$ " iron pipe. By means of a suitable arrangement of pressure tubing and valves, water was driven through the core, but the oil recovery was negligible. Approximately, three milliliters of liquefied propane was then driven through the same core under 210 p. s. i. g. inlet pressure (205 p. s. i. g. outlet pressure) by a flow (A) of water. The layer of propane plus dissolved oil passed under pressure into a closed chamber where it was isolated from the core. The pressure in this chamber was reduced and the propane (B) allowed to gasify through a tube into a gas collecting bottle. The oil remaining was washed out

of the chamber with pentane into a tared dish. After evaporation of the pentane on a steam bath, the oil residue in the dish was determined by weighing.

The quantity of propane (C) remaining in the core was determined by releasing to atmospheric pressure and by pumping under vacuum. The propane so released was collected and measured. Finally, the amount of residual oil in the treated core was determined by removing the core from the holder, powdering it in a mortar, and extracting with pentane in a Soxhlet extraction apparatus. Evaporation of the pentane yielded the residual oil. The results are tabulated below.

Table

Weight of core, grams	15.82
Volume of core, ml.	7.46
Propane charged, grams	1.5
Water charged (A), grams	10.0
Linear velocity of combined drive, feet/day	5.0
Propane recovered (B), per cent	74.3
Propane recovered (C), per cent	25.7
Oil recovered by propane, grams	0.095
Oil residue (by pentane extraction), grams	0.060
Weight-per cent oil recovered by propane	61.3

We claim:

1. In the recovery of oil from partially depleted oil-bearing formations, the improvement which consists of introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well while holding back pressure on an outlet well, forcing a layer of said liquefied hydrocarbon through the formation by means of water injection, and recovering gas and oil from the outlet well.

2. In the recovery of oil from partially depleted oil-bearing formations, the improvement which consists of introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well while holding back pressure on an outlet well, forcing a layer of said liquefied hydrocarbon through the formation by means of water injection while recovering gas and oil from the outlet well, and additionally reducing the pressure within the formation so as to increase the recovery of gas and oil from the outlet well.

3. In the recovery of oil from partially depleted oil-bearing formations, the improvement which consists of repeatedly introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well, while holding back pressure on an outlet well, and forcing a layer of said liquefied hydrocarbon through the formation by means of water injection while recovering gas and oil from the outlet well.

4. In the recovery of oil from partially depleted oil-bearing formations, the improvement which consists of repeatedly introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well, while holding back pressure on an outlet well, and forcing a layer of said liquefied hydrocarbon through the formation by means of water injection while recovering gas and oil from the outlet well, and additionally reducing the pressure within the formation so as to increase the recovery of gas and oil from the outlet well.

5. In the recovery of oil from partially depleted oil-bearing formations, the improvement which consists of introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well, while holding

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back pressure on an outlet well, forcing a layer of said liquefied hydrocarbon through the formation by means of water which contains a surface-active agent, and recovering gas and oil from the outlet well.

6. In the recovery of oil from partially depleted oil-bearing formations, the improvement which consists of introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well while holding back pressure on an outlet well, forcing a layer of said liquefied hydrocarbon through the formation by means of water which contains a surface-active agent, while recovering gas and oil from the outlet well, and additionally reducing pressure

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within the formation so as to increase the recovery of gas and oil from the outlet well.

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