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PETROLEUM PRODUCTION PROCESS

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2 Claims. (Cl. 166—21)

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Our invention relates to improvements in the recovery of oil from partially depleted oil-bearing formations. It is common knowledge that one of the major problems in the production of oil is increasing recovery of oil after primary flow and pumping methods are exhausted. Increased oil recovery is usually attempted by so-called secondary methods involving the use of gas to repressure the formation and drive additional oil from the retaining sands through output wells. In many instances, water drive also is resorted to in an effort to further increase recovery, but in all events total recovery by application of all these methods rarely exceeds 40 to 65 per cent. Application Serial No. 65,974 of December 17, 1948 by John W. Teter and Bernard S. Friedman describes development of a combined liquefied hydrocarbon gas and water drive that permits very favorable recoveries of residual oil, e. g. upwards of 80 to 90 per cent. The Teter and Friedman method contemplates injection of a normally gaseous hydrocarbon, e. g. propane, to the formation through one or more input wells under pressure conditions effecting liquefaction. The liquefied hydrocarbon is driven through the formation by water injection, and gas, recovered oil and water are recovered through one or more output wells located in proximity to the input well.

Our studies have confirmed the high recovery of residual oil possible by a combined liquefied hydrocarbon gas and water drive but have resulted in the discovery that application of the method under the usual and apparently most favorable conditions of operation results in unexpected pressure difficulties which substantially affect operating costs.

Ordinarily, movement of the liquefied hydrocarbon and water through the formation, that is the drive rate, is controlled by the input pressure. Drive rates which are as rapid as possible yet consistent with uniform flow through the formation are normally contemplated, e. g. from about 5 to 10 linear feet per day. Back pressure exceeding the vapor pressure of the liquefied hydrocarbon at ambient temperatures, e. g. 190 p. s. i. g. for propane at 100° F., is maintained on output wells. We have found that as the combined liquefied hydrocarbon and water drive gets under way and a liquefied hydrocarbon and water interface is formed within the formation, pressure drop across the formation builds up rapidly in such a way as to seriously interfere with movement of the drive components and to require excessive input pressures. We have found that the movement of the combined liquefied hydrocarbon and water in

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effect causes a large drop in the apparent permeability of the formation or a large increase in the viscosity of the drive liquids or both. We have found that the adverse change in the permeability-viscosity relationship is apparently associated with the trailing edge of the liquefied hydrocarbon charge, for use of a liquefied hydrocarbon drive alone or use of a water drive alone does not result in similar changes affecting pressure control. However, we have not been able to determine to date the cause of the difficulty although it may be associated with the so-called Jamin action. We also have found that relatively large amounts of the hydrocarbon are not recovered when the drive is conducted in the usual manner. For example, an amount of liquefied hydrocarbon may be employed in the drive corresponding to about one half the total void volume of the oil sands and the retention of the hydrocarbon or loss may approximate about 10 to 20 per cent of the void volume.

We have now found that pressure drop across the formation during the drive can be controlled within an acceptable limit by employing a very low drive rate, namely less than about 2 linear feet per day, and we also have found that recovery of liquefied hydrocarbon employed in the drive can be significantly improved by depressuring the water flooded formation at a carefully controlled rate so that the linear rate of flow of liquid from the formation will not exceed approximately 2 feet per day. Thus in one aspect, our invention relates to an improved method of applying a combined liquefied hydrocarbon and water drive in secondary recovery in order to avoid excessive pressure drop across the formation and maintain input pressure at a reasonable value, and in another aspect it relates to improvement in the recovery of the hydrocarbon pressuring agent by controlled depressurization upon completion of the drive.

According to our invention a liquefied hydrocarbon, particularly propane, is introduced to the partially depleted oil-bearing formation through an input well, while holding back pressure on an outlet well, the liquefied hydrocarbon is forced through the formation by means of water injection under conditions such that the linear velocity of the combined drive through the formation is limited to below about 2 feet per day. Oil and gas are recovered from the outlet well in the course of the drive, and, in a special modification of our invention, additional hydrocarbon employed in the drive is recovered upon completion of the drive by slow depressurization at a controlled rate such

that the pressure release is less than about 1 pound per square inch per hour, or below that permitting a flow rate exceeding about 2 feet per day.

In applying our invention to oil recovery, the partially depleted formation may have been subjected to previous conventional gas drive or to conventional water flow. In such instances the existing pattern of input and output outlet wells may be employed. Advantageously, a 5 spot or 9 spot pattern is adopted in order to promote uniformity of flow and reduce drive distances. The hydrocarbon selected for the drive is a readily volatile and advantageously a normally gaseous hydrocarbon such as a light alkane which will promote oil removal by good solubility and viscosity reduction combined with high vapor pressure for stripping action and ease of recovery. Propane is particularly useful. A butane is useful but ordinarily has greater value for other purposes and of course it has lower vapor pressure. Olefins also are too valuable for large scale use. Ethane and methane are useful but have high vapor pressures increasing the cost and difficulty of liquefaction. The hydrocarbon is introduced into the bed under conditions to insure liquefaction. Ordinarily back pressure is maintained at the outlet wells but where the field has been previously water flooded the permeability may be so low as to require only nominal control. The initial introduction of hydrocarbon may be effected rapidly, but at the point where water injection begins, the flow rate is reduced to less than about 2 linear feet per day, advantageously about 1 foot per day. The relative quantities of propane and water and the relation of these quantities to the void volume of the formation are not critical. In a typical formation, the void volume ascertained by core boring and analysis may approximate 30 to 35 per cent, and the proportion of liquefied hydrocarbon to the formation void volume may approximate 1:2 to 2:1, for example. Usually the per cent of residual oil as obtained by core analysis is considered and the ratio of liquefied hydrocarbon to oil may approximate from about 2:1 to about 10:1 by volume. The relation of water to propane may approximate 3 or 4 to 1.

In order to obtain maximum recovery of residual oil from the formation, the combined liquefied hydrocarbon and water drive may be repeated for a number of cycles although a single cycle ordinarily removes the bulk of the economically recoverable oil. When the water drive has been completed, it is advantageous to depressure the field in order to recover the hydrocarbon driving medium maintained in the formation. Advantageously, depressurization is carried out by continuing water injection and slowly reducing the pressure on the outlet wells to atmospheric pressure. As the pressure approaches the critical zone of the vapor pressure of the liquefied hydrocarbon at ambient temperatures, e. g. 190 p. s. i. g. for propane at 100° F. special care should be exercised to maintain a rate of pressure decrease below about 1 to 2 p. s. i. g. per hour. Thus for propane in the region 210 to 200 p. s. i. g., it is advantageous to limit the rate of pressure drop to about 0.01 to 0.1 p. s. i. g. per hour. In this way, the linear rate of flow of liquid from the formation is maintained under approximately 2 feet per day, and holdup within the formation is reduced to insubstantial quantities.

The principles of our invention will be further illustrated by reference to the following experi-

mental data developed on actual sand cores obtained from a sandstone formation where primary methods of recovery had been abandoned and secondary methods including water flooding had been practiced. The cores selected were cemented in a metal core holder by means of Sauereisen cement and had the following physical characteristics.

Drilled.....	1,937.
Diameter.....	42.6 mm. (1.68 inches).
Length.....	184.5 mm. (7.26 inches).
Volume.....	262 cc.
Weight.....	524 grams.
A. D.....	2.0
Porosity.....	20% avg. (determined in 1937).
Weight percent oil.....	3.7 (determined in 1937 but substantially reduced by atmospheric exposure).
Void vol.....	52.5 cc.
Nitrogen permeability.....	38.5 mdes.

The core was first put under water flood at a linear rate of 0.85 foot per day. The average liquid permeability of the core after complete water flood was 2.0 millidarcies. Two propane-water drives were then made on the water-flooded core. The drives were of limited extent and the second propane-water drive was conducted after intermediate water-flooding. The results on the drives follow:

	H ₂ O Flood	1st C ₃ H ₈ O Drive	2nd C ₃ H ₈ O Drive
Weight of Core.....	524	524	524
Void Volume.....	52.5	52.5	52.5
Volume of Core.....	262	262	262
Propane Charged (gr.).....		14.52	14.19
H ₂ O Charged (gr.).....	104.5	105	145
H ₂ O Charged (cc.).....	104.5	105	145
Propane Charged (cc.).....		29.04	28.39
Linear Rate of Charging (Ft./Day).....	.846	1.32	1.25
Average $K/\mu \times 10^{-4}$	22.5	35	37
Ratio of Sand Volume/Propane (Vol.).....		9.02	9.24
Ratio of Sand Voids/Propane (Vol.).....		1.80	1.85
Ratio of Sand/C ₃ (Wt.).....		36.1	36.9
Ratio of Sand/Water (Vol.).....	2.5	2.5	1.8
Ratio of Sand Voids/Water (Vol.).....	.5	.5	.36
Oil Produced Water Flood.....	Trace		
Oil Produced by C ₃ -H ₂ O Flood (gr.).....		2.95	1.84
Oil Produced by C ₃ -H ₂ O Flood (cc.); Est. Sp. G=88.....		3.35	2.10

In these drives at low rates, it was unexpectedly determined that steady relationship was maintained between apparent permeability of the sand and the viscosity of the drive media, represented as K/μ , under the slow drive rate conditions. In previous experiments at linear rates averaging about 7 feet per day, the ratio of permeability to viscosity dropped off as much as 200 per cent and pressure drops of upwards of 20 pounds per foot developed.

In a repeat test drive on another actual sand core, the highly beneficial effect of maintaining the combined water-propane drive rate within the low range of 0.5 to 2.0 feet per day was confirmed. Build up in pressure drop across the oil containing sand was avoided, and the original apparent relationship between permeability and viscosity was maintained. Propane recovery by slow depressuring while flowing water through the core resulted in a recovery of 31.8 weight per cent in addition to the amount of propane, 60.3 weight per cent, recovered in the course of the pressuring drive. The balance of 7.9 weight per cent was recovered by applying vacuum to both ends of the core and by application of a nitrogen drive.

Hence our invention provides means for effecting important economies in the operating pressures required and in the recovery of the hydrocarbon driving agent employed, by reversing the

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apparently desirable trend in the pressures and internal flow rates in the recovery of oil from partially depleted formations by a combined water and propane drive.

We claim:

1. In the recovery of oil from partially depleted oil-bearing formations by introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well while maintaining back pressure on an outlet well, forcing the liquefied hydrocarbon through the formation by water drive and recovering oil and gas from an outlet well, the improvement which comprises maintaining the linear velocity of the combined drive through the formation at a rate below about 2 feet per day.

2. In the recovery of oil from partially depleted oil-bearing formations by introducing a liquefied normally gaseous low molecular weight hydrocarbon to the formation through an input well while maintaining back pressure on an outlet well, forcing the liquefied hydrocarbon through the formation by water drive and recov-

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ering oil and gas from an outlet well, the improvement which comprises maintaining the linear velocity of the combined drive through the formation at a rate below about 2 feet per day and slowly depressuring the resultant water flooded formation at the outlet well to atmospheric pressure upon completion of the drive at a controlled rate which maintains the linear rate of flow of liquid from the formation below about 2 feet per day thereby enabling substantial recovery of said liquefied normally gaseous low molecular weight hydrocarbon.

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BERNARD S. FRIEDMAN.

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