

[54] **OIL RECOVERY BY OVERLYING COMBUSTION AND HOT WATER DRIVES**

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[51] Int. Cl. **E21b 43/24**

[58] Field of Search..... **166/258, 261, 272, 166/303, 268, 266, 269**

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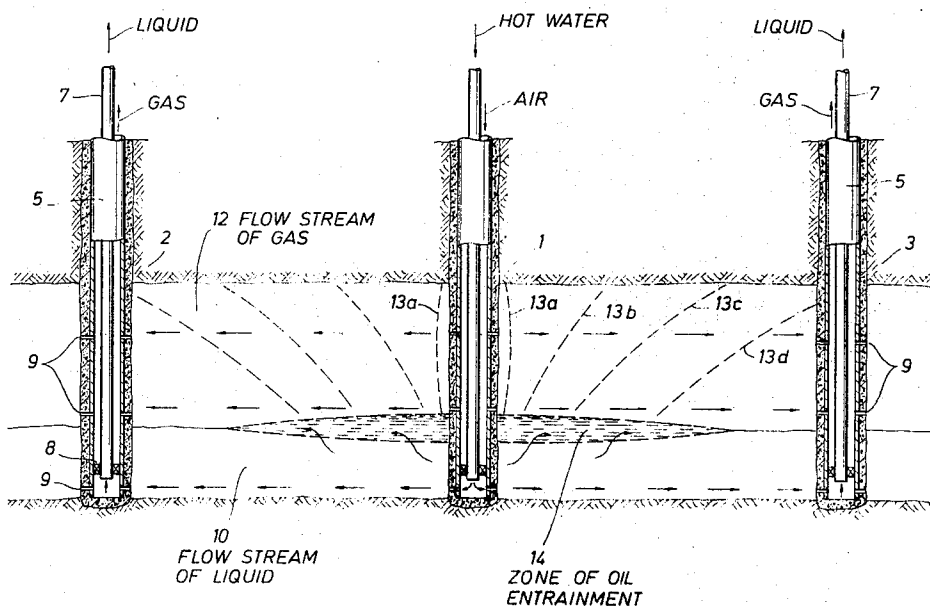
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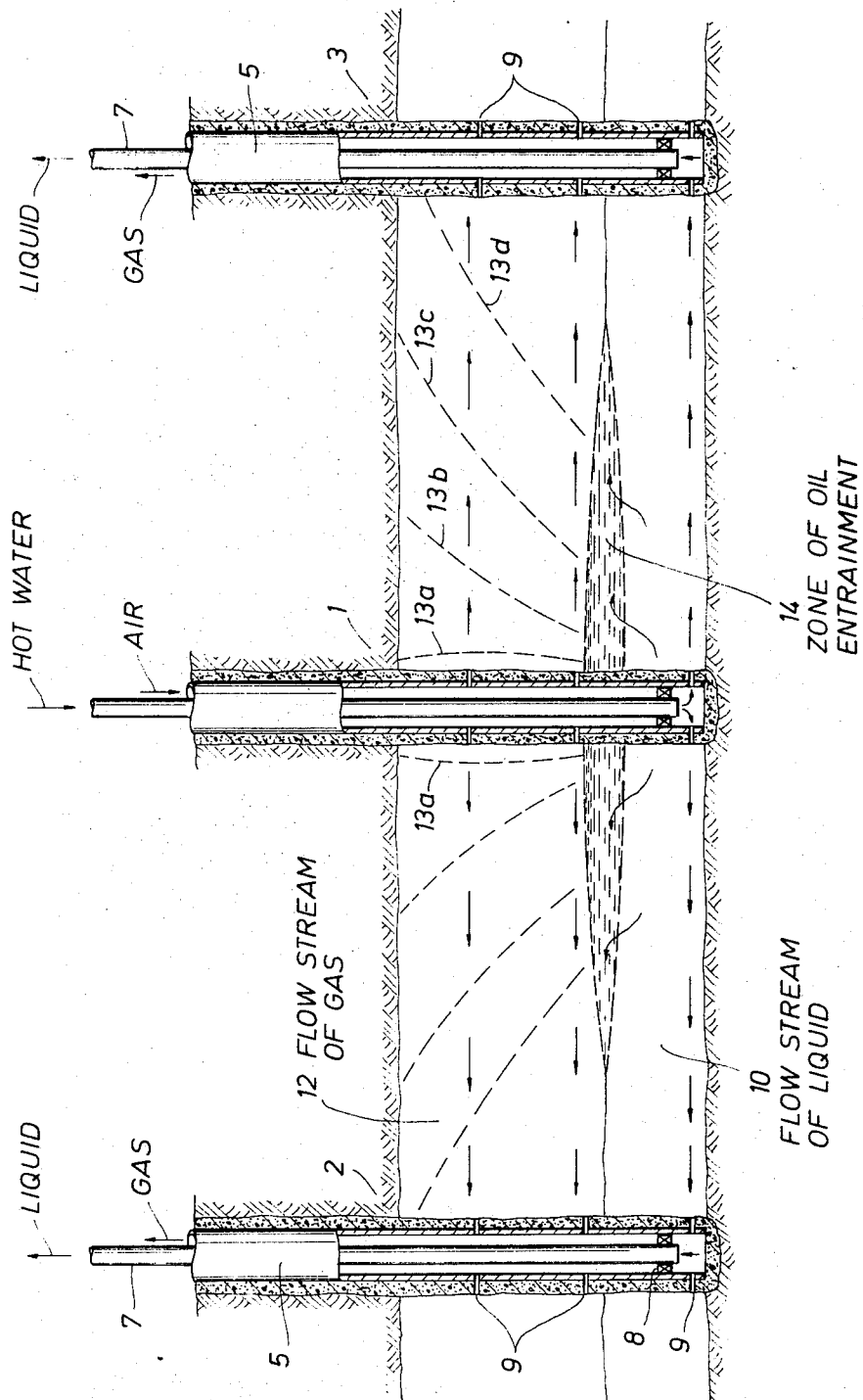
Primary Examiner—Stephen J. Novosad
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[57] **ABSTRACT**

In recovering a viscous oil from a reservoir in which the initial effective permeability to an injected fluid increases with increasing depth, a hot liquid is flowed between injection and production locations in the lower portion of the reservoir before or during the advancing of a combustion front between injection and production locations in the upper portion of the reservoir. Petroleum materials are recovered from the fluids produced from the upper and/or lower portions of the reservoir.

6 Claims, 1 Drawing Figure





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INVENTORS

OIL RECOVERY BY OVERLYING COMBUSTION AND HOT WATER DRIVES

BACKGROUND OF THE INVENTION

This invention relates to recovering viscous oils or tars from reservoirs which have a relatively high vertical permeability and a horizontal permeability which increases with increases in depth, such as the Peace River tar reservoir in Canada.

It is known that in recovering a viscous oil it is desirable to reduce the viscosity of the oil within the reservoir by heating it or diluting it with a less viscous solvent. The solvent dilution tends to be relatively expensive. An underground combustion provides a particularly attractive method for thermally reducing the viscosity of such a reservoir oil.

However, in a reservoir in which the permeability increases with depth, for example, due to an oil saturation which decreases with depth, the oil recovery efficiency of an underground combustion drive process tends to be relatively low. The combustion front and the hot combustion products tend to gravitate toward the upper portion of the reservoir and bypass relatively large portions of oil or tar that is initially heated to a mobility that allows it to move into the lower portion of the reservoir, where it cools and accumulates in banks or zones of high concentration that are bypassed and left within the reservoir. Furthermore, these banks or zones of high crude concentration tend to cool and become more concentrated as they move towards production locations, and often effectively plug the formation.

U.S. Pat. No. 3,439,742 by R. W. Durie describes an oil drainage type of oil recovery process designed for use in a reservoir having a permeability that increases with depth. In that process a hot fluid, such as steam, is selectively injected into the lower portion of the reservoir while fluid is selectively produced from the lower portion of the reservoir. The specified selective injection and production procedure causes a reservoir heating fluid such as steam to remain in the lowlying channel (of relatively high permeability) as it flows between the injection and production locations (although the steam has a lower specific gravity than the other fluids in the reservoir). The steam heats the oil in the lower portion of the reservoir until it becomes mobile and is displaced to the production location. In order to produce oil from the upper portion of the reservoir the zone of high permeability must be expanded upward by a continued leaching out of oil and an upward migration of the steam boundary. Where the reservoir is relatively thick, such an upward expansion of a heated zone tends to be undesirably slow and expensive.

U.S. Pat. No. 3,467,191 by Van Daalen, Van Domselaar, and Hooykaas describes a generally vertical drive procedure designed for use in reservoirs having a permeability that increases with depth. In conducting that process by reducing the oil viscosity by an underground combustion, a combustion front is advanced between injection and production locations within the upper portion of the reservoir. After a heated channel of high permeability has been established in the upper zone, a liquid having a specific gravity exceeding that of the reservoir oil is injected into the lower portion of the reservoir to gravitate below the oil and lift it toward the hot zone. Where the areal extent of the reservoir is

significant, such an oil-lifting requires the injection of the relatively dense liquid in an amount sufficient to fill substantially the entire reservoir, and this may become undesirably expensive.

SUMMARY OF THE INVENTION

This invention is a process for recovering oil from a reservoir that contains a viscous oil or tar and has an effective permeability to water that increases with increasing depth. A hot relatively high density liquid is flowed between injection and production locations within the lower portion of the reservoir. Concurrently, and/or subsequently a combustion front is advanced between injection and production locations within the upper portion of the reservoir. The rates of flowing and heating the fluids are correlated so that combustion supporting and combustion produced gases tend to flow through the upper portion of the reservoir while oil that is heated by them drains into the lower portion and so that oil in the lower portion of the reservoir becomes entrained in the hot relatively high density liquid that flows through the lower portion of the reservoir. Petroleum materials are recovered from the fluids produced from the reservoir.

DESCRIPTION OF THE DRAWING

The drawing is a schematic cross-sectional illustration of a reservoir and an arrangement of wells and well equipment in which the invention is being employed.

DESCRIPTION OF THE INVENTION

In the drawing, injection well 1 and production wells 2 and 3 are completed within reservoir 4. Reservoir 4 contains fluids such as connate water and viscous oil or tar, with the water saturation and the effective water permeability of the reservoir increases with increasing depth. The wells are each equipped with grouted casings 5, tubings 7, downhole packers 8 (that surround the tubings and can be closed to seal the casing annuli) casing perforations 9, and associated fluid handling and fluid controlling surface equipment, not shown. Such wells can be drilled and completed by means of known techniques and equipment.

In initiating the operation of the present invention, a relatively dense liquid, such as water or brine, is flowed between injection and production locations within the lower portion of the reservoir in a flow stream 10 as indicated by the arrows. Such a flow is effected by injecting liquid through the tubing string and lower perforation of injection well 1 while producing liquid through the lower perforations and pumping it out through the tubing strings of production wells 2 and 3. This applies a surface pump injection pressure plus the hydraulic head of the column of liquid to the fluids in reservoir 4 near well 1 and pumps down the pressure in and near wells 2 and 3 to less than the hydrostatic pressure. During the initiation of such a flow the packers 8 are preferably seated so that such pressure increases and decreases are applied predominantly adjacent to the bottom perforations.

In an early stage the liquid which is injected to initiate the flow is preferably injected at the ambient reservoir temperature. After flow in zone 10 has been established the liquid flowing in such a stream is

preferably heated at a relatively slow rate so that the temperature within the reservoir is raised all along the flow stream until the temperature of the flowing liquid is sufficient to thermally mobilize the reservoir oil. Such a slow heat-up of the relatively dense liquid is particularly important where the reservoir contains a highly viscous and relatively dense tar, such as that contained in the Peace River formation in Canada. If the first injected portion of the liquid is relatively hot, it tends to mobilize and displace the first contacted portions of the tar then lose heat before the tar reaches the production location, thus causing a bank of initially mobilized then cooled tar to be bypassed by the liquid stream. Where the first injected portion of liquid is relatively cool and the temperature is slowly raised, the liquid initially flows around tar without displacing it and substantially none is displaced until the temperature of the entire flow path has been raised to a temperature at which the tar is mobile.

Substantially concurrent with (and preferably during or after) the initiation of such a flow of heated liquid within the lower portion of the reservoir, a flow of gas is initiated within the upper portion of the reservoir. The gas flow is preferably initiated by injecting gas through the casing and upper perforations of well 1 while producing fluid through the upper perforations, casings and tubing strings of wells 2 and 3. During the gas production operations in wells 2 and 3, the packers 8 are preferably unseated so that a substantially instantaneous gravity segregation occurs in the annulus (between the tubing and casing strings) with liquid gravitating toward the bottom of the well and entering the tubing string while gas rises within the casing annulus. The outflowing of the liquid pumped up through the tubing strings and the gas rising within the casing annulus is preferably controlled so that a backpressure is held on the gas while the liquid is pumped out at a rate that reduces the pressure in the formation near the bottom of the production wells. In general, substantially any arrangement can be used as long as a combustion front is advanced between injection and production locations in the upper portion of the reservoir while (or substantially while) a hot and relatively dense liquid is flowed between injection and production locations in the lower portion of the reservoir.

In the operation shown, a forward combustion fluid drive has been initiated by adjusting the composition of the gas being injected through well 1 and circulated through flow stream 12 as required to circulate a combustion supporting gas. As known to those skilled in the art, the initiation and/or supplementation of the underground combustion can be effected by heating the oil in the reservoir around the injection well and/or injecting fuel prior to or during the advance of the combustion front. As the front advances, it temporarily occupies positions such as those shown by the dashed lines 13a and 13d.

Relative to a conventional forward combustion drive, the present process is uniquely effective with respect to keeping the hot gases from bypassing oil or tar that becomes concentrated near the lower portion of the reservoir. In an underground combustion, the combustion products include the pyrolysis products of the organic material in the reservoir, unreacted combustion supporting gas, vaporized water

and petroleum materials, etc. The combustion products are heated, at or near the combustion front, to temperatures in the order of about 800°F or more and have a relatively high mobility and a relatively low density.

The reservoir oil, which is heated by the combustion reaction or contact with the combustion products, becomes mobile and gravitates below the combustion products. In a conventional process, the mobilized oil tends to cool and form a bypassed bank as soon as it moves down into a cooler portion of the reservoir. In contrast, in the present process, the mobilized oil moves downward into another hot zone where it is entrained in a flowing hot liquid that keeps it mobile and displaces it into the production zone. Such an oil entrainment occurs in a zone 14 near the junction of the liquid and gas flow streams 10 and 12. In the well pattern shown, the entrainment zone 14 expands radially as the combustion front expands radially through positions such as 13a and 13d.

Alternatively, the combustion supporting gas can be injected through well 1 and flowed in the direction shown after combustion fronts have been initiated near wells 2 and 3 in order to effect a reverse combustion drive in which the direction of a combustion front advance is opposite that shown. The combustion fronts can also be initiated near wells 2 and 3 and advanced by injecting combustion supporting gases through those wells to effect a forward combustion drive, which advances in a direction opposite that shown. Or, substantially any procedure can be utilized for advancing a combustion front between injection and production locations within the upper zone.

The present process can advantageously utilize a plurality of injection and production wells in substantially any pattern and can be initiated or conducted by known procedures for effecting the combustion drives and oil recoveries. The combustion supporting fluid which is injected to advance the combustion front can advantageously contain aqueous liquid in a proportion sufficient to provide a "wet" combustion process. In the present process, such an injection of liquid tends to cause a liquid phase to gravitate downward and provide a down-flowing liquid phase that enters the oil entrainment zone 14 from the top. This enhances the movement of the oil into the liquid flow stream 10. The fluid produced at the production location in the upper portion of the reservoir is preferably treated to recover any petroleum materials it may contain.

The liquid which is circulated through the lower portion of the reservoir can comprise substantially any liquid having a density at least substantially equal to that of the reservoir oil at a temperature at which the reservoir oil is relatively mobile. Such reservoir oils and tars are generally sufficiently mobile at a temperature at which their viscosity is less than about 50 centipoises. The circulated liquid is preferably an aqueous liquid, such as a relatively soft water or brine, but can be substantially any liquid which is adequately non-scaling and non-corrosive with respect to the well equipment. The circulated liquid can be heated in surface located water heaters, heat exchangers, boilers, or the like and/or downhole heaters or heat exchangers. Particularly in the initial stages of the initiation of the liquid circulation, the composition of the circulating liquid can be adjusted to provide increasing concentra-

tions of an oil or rock reactive component that causes a chemical heating within the path of the flow stream (e.g., by employing increasing concentrations of an acid such as sulfuric or nitric acid, or the like). In a preferred operating procedure, the produced hot liquid is treated to recover petroleum materials and the remaining liquid is reheated and recycled through the reservoir. The oil recovery, heating, and treating of the circulated heated liquid can be effected by means of known techniques and equipment.

In a preferred embodiment, after a flow of liquid has been initiated within zone 10, and the temperature of the liquid has been raised to substantially a temperature at which the reservoir oil is mobile, steam is injected through the injection locations within the lower portion of the reservoir. The steam is preferably dry, wet or low grade steam injected at a rate and pressure such that substantially all of the fluid entering the reservoir is liquid.

In circulating the heated liquid through the lower portion of the reservoir, the rate of heating and the rate of liquid flowing is preferably correlated to maintain a temperature at but not significantly above a temperature at which the oil or tar becomes sufficiently mobile to permit a good rate of circulation at a relatively low injection pressure. In the upper portion of the reservoir, the gas injection pressures and gas backflow pressures should be adjusted to maintain a pressure at which substantially all of the circulated heated liquid is liquid within the reservoir at the temperature at which the circulation is being conducted. The injection pressure applied to the circulating heated liquid is preferably high enough to provide an oil-displacing driving force or pressure gradient that decreases from the points of injection to the points of production within the lower portion of the reservoir but low enough to maintain a thermal economy by avoiding severe heat losses to the earth formations above and below the reservoir formation.

In a preferred embodiment, after a combustion front has been advanced at least one time through the reservoir (for example, from the injection to the production locations in the upper portion), the combustion front advancing operation is curtailed by substantially reducing or completely terminating the injection of combustion supporting gas while terminating the production of gas. Such a curtailment is advantageously effected by terminating the production of gas and reducing the rate of gas injection to that required to maintain a relatively high pressure within the upper portion of the reservoir. Such a pressure is advantageous in enhancing the rate of gravity drainage of the heated oil

into the flow stream 10 through which the heated liquid is circulating.

What is claimed is:

1. A process for recovering oil from a reservoir that contains a viscous oil, has an effective aqueous fluid permeability and aqueous liquid saturation that increases with increasing depth, and is penetrated by injection and production wells equipped with means for injecting and producing fluids, which process comprises:

flowing a relatively high density hot aqueous liquid substantially horizontally from injection to production locations within a lower portion of the reservoir with the injected liquid having a temperature sufficient to thermally mobilize reservoir oil that is contacted by the liquid and a density that is at least substantially equal to that of the reservoir oil at the oil mobilizing temperature;

injecting combustion supporting fluid into the upper portion of the reservoir to advance an underground combustion front substantially horizontally between injection and production locations within the upper portion of the reservoir while displacing gas phase fluids through the upper portion and displacing thermally mobilized liquid phase petroleum materials toward the lower portion of the reservoir; and

2. The process of claim 1 in which said combustion supporting fluid contains a mixture of oxygen and aqueous liquid.

3. The process of claim 1 in which said liquid is flowed through the lower portion of the reservoir in substantially the same direction as said combustion supporting fluid is flowed through the upper portion of the reservoir and said combustion front is advanced.

4. The process of claim 1 in which gaseous and liquid fluids are separated in downhole locations within the wells and are produced from the reservoir in separate streams having separately controlled resistances to their outflow from the reservoir.

5. The process of claim 1 in which said liquid is flowed through the lower portion of the reservoir in substantially the opposite direction as said combustion supporting fluid is flowed through the upper portion of the reservoir and said combustion front is advanced.

6. The process of claim 1 in which steam is injected into the lower portion of the reservoir to condense and form said relatively high density liquid which is flowed from injection to production locations and is injected at a rate and pressure such that substantially all of the fluid entering the reservoir is liquid.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,727,686 Dated APRIL 17, 1973

Inventor(s) MICHAEL PRATS, WILLEM F. ENGELBERTS (DECEASED) BY

CATHERINA H. ENGELBERTS (PERSONAL R)

It is certified that error appears in the above-identified patent
and that said Letters Patent are hereby corrected as shown below:

In claim 1 the last paragraph should read:

"recovering petroleum materials from fluids
produced from the reservoir."

Signed and sealed this 11th day of June 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents