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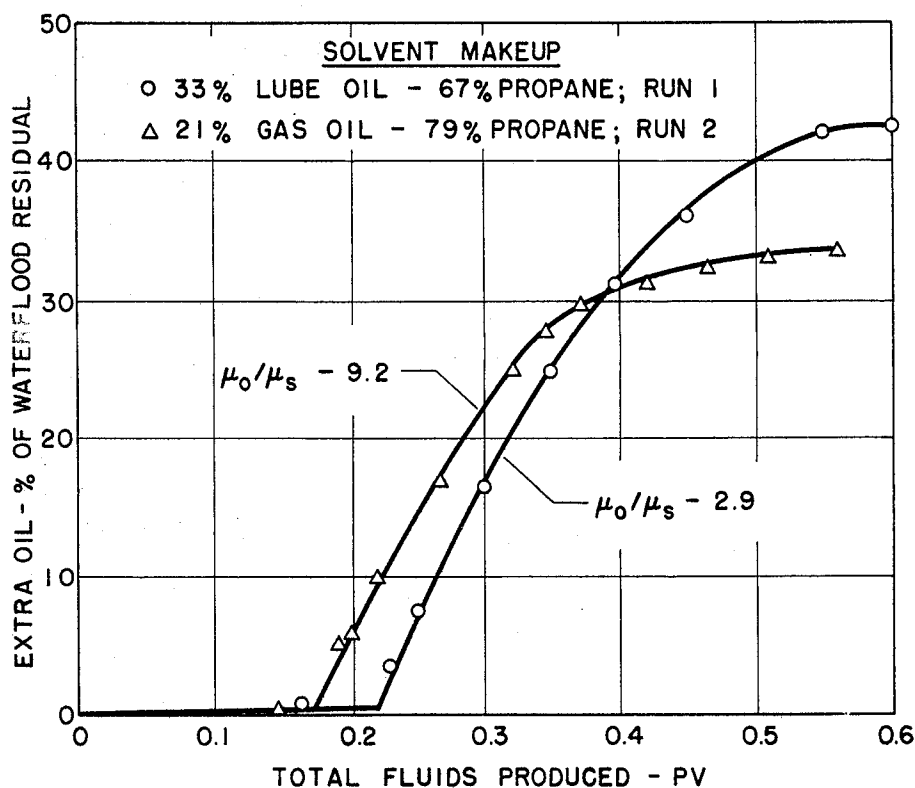
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RECOVERY OF WATERFLOOD RESIDUAL OIL

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PVC EFFECTIVELY RECOVERS TERTIARY OIL



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RECOVERY OF WATERFLOOD RESIDUAL OIL
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This invention is concerned with a method for increasing the recovery of crude petroleum from subterranean reservoirs. It is particularly concerned with a method of recovering additional oil from a reservoir that has been depleted both by primary production and then by waterflooding. Specifically the invention is directed to the use of an improved solvent composition for carrying out a miscible displacement recovery process.

In its broadest aspect, the invention comprises the steps of injecting a blend of liquid propane and a highly viscous petroleum distillate oil into a partially depleted oil-bearing reservoir, driving the blend from the input well toward a production well, and producing displaced reservoir crude from the production well.

In a more limited embodiment, the process comprises the steps of injecting a blend of liquid propane and heavy, vacuum distilled gas oil into a waterflooded oil-bearing reservoir, driving the blend from the input well toward a production well by injecting additional water through the input well, producing displaced reservoir crude from the production well, and then recovering injected propane by depressuring the reservoir. A subterranean oil reservoir in the initial phase of its producing life generally produces oil as a result of innate gas pressure, rock pressure or water pressure. Thus when a well first penetrates the reservoir, the innate pressure drives oil from the reservoir to the well bore and thence to the earth's surface. A pump is frequently used to aid in the removal of oil from the well bore and to reduce back pressure on the formation. This phase of the producing history of an oil well is generally referred to as its primary production phase or period.

Once the reservoir pressure has dropped to an extent such that it is no longer possible to produce oil from the reservoir at a practical rate, it has been the practice in the petroleum industry to resort to one or more secondary recovery procedures. These procedures for the most part consist of injecting a fluid into one or more wells in any particular reservoir and thereby displacing oil from the injection wells toward adjacent producing wells in the same reservoir. Fluids that are used or have been suggested for this purpose include water, brine, aqueous surfactant solutions, liquefied petroleum gas, carbon dioxide, air, combustion gases, and the like. The fluid that is probably most widely employed for this purpose is water.

When water is used to flood an oil field, it has been determined that the water drive is not completely effective in recovering all of the oil that is left in the field following the primary production stage. At this point it is well to note that from 60% to 80% of the oil in a given field or reservoir is usually left within the reservoir after primary production has ceased to be feasible. It has further now been determined that only up to about 50% of the remaining oil is recoverable by secondary recovery in the form of waterflooding. It is apparent that a considerable amount of oil still remains in most reservoirs even though primary recovery and waterflooding have both been completely utilized.

Various schemes have been proposed for recovering

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residual waterflood oil, and among those more prominently mentioned has been the use of solvents boiling in the liquefied petroleum gas range. A miscible displacement drive carried out by injecting liquid propane or butane, for example, serves in part as an extraction agent, so as to improve the ultimate oil recovery. The potentialities of this technique, however, are seriously limited by practical or economic considerations. It has been found that the solvent requirements to obtain complete oil recovery are prohibitively excessive. It becomes impractical to inject sufficient solvent to attain complete oil recovery due to the expense of the large volumes of solvent required.

The maximum amount of solvent which can practically be employed in secondary recovery operations is about 0.3 pore volume of solvent. In other words, an amount of solvent can be contemplated which is about one-third of the total pore volume of the particular reservoir. Use of quantities beyond this limitation becomes impractical.

A partial solution to the problem of miscible displacement economics has been developed in recent years, which involves the injection of a bank of miscible fluid such as LPG, followed by the injection of a driving fluid to push the miscible bank through the reservoir. Thus, the LPG is first injected into a reservoir through one or more injection wells and a second fluid is thereafter injected into the reservoir so as to drive the first fluid through the reservoir toward one or more spaced production points. The oil miscible fluid mixes with the reservoir oil, reduces its viscosity thereby increasing its mobility, scavenges the oil from the reservoir and moves it toward the production well. Water has been employed as a fluid for driving an LPG bank through a reservoir.

Another, more serious problem arises, even when using such modified miscible displacement drives as following LPG with water. In most cases, such miscible displacement drives result in contacting only 10% to 25% of the formation volume. That is, 75% to 90% of the formation is bypassed by the solvent drive because of gravity over-riding and viscous fingering.

The solvent bank is followed by injecting a propellant fluid at the input well to drive the solvent through the reservoir, and to displace or scavenge the solvent from the formation. Natural gas, flue gas, or steam are suitable; however, water is preferred. Similarly as with initial waterflooding, the water injected to drive the solvent is an inefficient displacing agent because of its immiscibility, bypassing more than half the hydrocarbon volume. Because of such poor recovery performance, it has been determined that a volatile solvent is essential to ensure successful operation, from a practical viewpoint. That portion of a volatile solvent which remains in the reservoir after scavenging with water can be readily subjected to further recovery by depressuring the reservoir, thus volatilizing the solvent, whereby a substantially greater recovery is realized.

Accordingly, the selection of a solvent for conducting a miscible displacement drive has involved a compromise between heavier, more viscous solvents which efficiently displace the crude oil but are themselves difficult to recover, and the less dense, less viscous, volatile solvents which are themselves easily recovered, but which do not efficiently displace crude from the reservoir.

In accordance with this invention a method is provided for increasing the viscosity and the density of a volatile driving solvent, without seriously limiting its ease of recovery. The increase is achieved by blending with liquid

propane a vacuum distilled thickening oil having a true boiling point distillation range of 680°–1250° F. and a viscosity of 200–6,000 cps. at 100° F. Preferably, the oil has an average boiling temperature of about 950° F., corrected to atmospheric pressure, and a viscosity of about 1,500 cps. at 100° F. It may be obtained directly from crude petroleum, or from heavy cracked stock.

The preferred thickening oil is a distillate petroleum fraction known as "heavy vacuum gas oil" which has a true boiling range between 800° F. and 1200° F., with viscosities ranging from 200 to 6,000 centipoises at 100° F., depending upon its chemical composition and the specific boiling range of the gas-oil. Laboratory tests have demonstrated that a mixture of 2 parts propane and 1 part heavy vacuum gas-oil has a viscosity of 1.94 centipoises at 92° F. and 1500 p.s.i.a. Solvent blends containing 50% to 99% propane are suitable, with 60% to 90% being preferred.

A bottoms fraction from the distillation of a crude oil is generally unsuitable for use as a propane thickener, because of the presence of excessive amounts of asphaltenes, resins, and other complex materials which precipitate upon the blending of such a fraction with any substantial amount of propane. Accordingly, a distillate fraction is required.

Although the heavy gas oils are a distillate fraction, they also frequently contain appreciable quantities of asphaltenes and resins. Blending of such oils with excess propane can lead to precipitation of the asphaltenes and resins, with a consequent partial loss of the desired increase in viscosity. Plugging of the injection well could also occur. Accordingly, a pressure vessel and suitable temperature levels should be provided to allow gravity separation of the precipitable material.

Another refinery product which has been found suitable for use in accordance with the purposes of the invention, as a thickener for propane, is a brightstock lubricating oil. Brightstock is a dewaxed high-viscosity lubricating oil blending stock, having a true boiling point generally within the range of 800° to 1200° F., and a viscosity ranging from 400 to 2000 cps. at 100° F., depending upon the composition of the specific stock. Brightstock may be considered an intermediary refined product of heavy vacuum gas oil.

The validity of the benefits of viscosity thickening was demonstrated in a laboratory model comprising a Torpedo sandstone 2 inches thick and 4 feet between wells and in the shape of 1/8 of a five-spot pattern. The model was saturated with crude petroleum and connate salt water and was then water driven to a residual oil saturation of 36% pore volume. A 3/10 pore volume slug of the above propane gas-oil mixture was injected followed by 0.43 pore volume of water, which was the volume of water required to establish a water-to-oil production ratio of 20:1. Total production, exclusive of water, consisted of 15.2% pore volume of crude petroleum and a 17.4% pore volume recovery of the propane gas-oil mixture.

Upon depressuring the model an additional 2.9% pore volume of oil was produced as well as 9.1% pore volume of propane and .7% pore volume of gas-oil.

This particular procedure is well adapted to shallow formations since the producing well can be pulled down to 100 to 150 p.s.i. and still have the propane in solution, thus allowing a high differential driving pressure. Hydrocarbons lighter than propane are not suitable since the solubility of the thickening oil therein would be inadequate. Nor are hydrocarbons heavier than propane applicable as it would be impractical to recover butane and heavier hydrocarbons by depressuring the reservoir.

Additional displacement experiments were run, using the above Torpedo sandstone model, and a simulated waterflood residual crude saturation of about 0.3 pore volume. In the first run, the solvent composition consisted of 33% brightstock lubricating oil, by volume, and 67%

propane. In the second run, the solvent consisted of 21% deasphalted heavy gas oil, by volume, and 79% propane.

The data are summarized in the accompanying graph, which shows that the ultimate recovery of waterflood residual oil is enhanced by a reduction in the viscosity ratio, i.e., the ratio of crude oil viscosity to solvent viscosity (μ_o/μ_s). In both runs the oil was recovered in about 0.5 pore volume of total produced fluids. The ratio of solvent injected to oil recovered increased as the oil to solvent viscosity ratio increased, indicating that solvent bypassing is reduced by the method of the present invention.

The particular sample of brightstock employed in the above experiments had a gravity of 28.3° A.P.I. at 73° F., and a viscosity of 918 cps. at 85° F. The gas oil employed in the experiments had a gravity of 22.5° A.P.I. at 124° F., and a viscosity before deasphalting of 5,540 cps. at 84.3° F. Because the properties of such propane-viscous oil blends are in many respects similar to the properties of volatile crude oil, the solvent blends of the invention have been nicknamed "pseudo volatile crude," the abbreviation for which is "PVC."

What is claimed is:

1. A process for recovering oil from a subterranean oil-bearing reservoir penetrated by two laterally spaced wells, which comprises injecting a bank of solvent through one of said wells into said reservoir, following said solvent with the injection of a scavenging and propelling fluid, and withdrawing oil from the other of said wells, said solvent consisting essentially of a blend of liquid propane and a highly viscous distillate oil, said distillate oil having a true boiling range between 680° and 1250° F. and a viscosity of 200 to 6000 centipoises at 100° F.

2. A process for recovering oil from a subterranean oil-bearing reservoir penetrated by an injection well and a production well laterally spaced therefrom, said reservoir having been partially depleted by primary production and then by waterflooding, which comprises injecting a bank of solvent through said injection well into said reservoir, said solvent consisting essentially of a blend of liquid propane and a highly viscous distillate oil, said distillate oil having a true boiling range between 680° and 1250° F. and a viscosity of 200 to 6000 centipoises at 100° F., following said solvent with the injection of water through said injection well as a propelling fluid, withdrawing oil from said production well, continuing the injection of said propelling fluid through said injection well, and continuing the production of fluids from said producing well until the major portion of said solvent bank has been produced therefrom, then depressuring said reservoir, thereby recovering the bulk of residual propane from said reservoir.

3. A process as defined by claim 2 wherein said blend of propane and distillate oil comprises 60 to 90 percent propane by volume.

4. A process as defined by claim 3 wherein said distillate oil is a heavy vacuum gas oil having a true boiling range between 800° and 1200° F. and a viscosity ranging from 200 to 6,000 centipoises at 100° F.

5. A process as defined by claim 3 wherein said distillate oil is a brightstock lubricating oil stock having a true boiling range between 800° and 1200° F., and a viscosity between 400 and 2000 cps. at 100° F.

6. A process for recovering oil from a subterranean oil-bearing reservoir penetrated by two spaced wells which comprises injecting a bank of solvent through one of said wells into said reservoir, following said solvent with the injection of a scavenging and propelling fluid, and withdrawing oil from the other of said wells, said solvent comprising a blend of 60% to 90% liquid propane by volume, and a highly viscous distillate oil having a true boiling range between 680° and 1250° F. and a viscosity of 200 to 6000 centipoises at 100° F.

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7. A process for recovering oil from a subterranean oil-bearing reservoir penetrated by two laterally spaced wells, which comprises injecting a bank of solvent through one of said wells into said reservoir, following said solvent with the injection of a scavenging and propelling fluid, and withdrawing oil from the other of said wells, said solvent comprising a blend of at least 60% liquid propane by volume and a distillate oil having a true boiling range between 680° and 1250° F. and a viscosity of 200 to 6000 centipoises at 100° F.

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