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SECONDARY RECOVERY PROCESS WITH
GAS-LIQUID DRIVE AGENTS

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This invention relates to the recovery of petroleum from reservoirs beneath the surface of the earth, and is more particularly concerned with a flooding process for recovering petroleum in greater amounts than is possible by conventional flooding methods.

It is well known in the secondary recovery art to inject a slug of fluid which is miscible with both the petroleum oil and the water phases in the reservoir, and to drive the slug of fluid through the reservoir by injecting floodwater behind it. Typical of the fluids used in such secondary recovery processes are the lower alcohols. When the fluid is an alcohol, for example, and it is attempted to form and maintain zones of oil-alcohol and water-alcohol miscibility, with a buffer zone of alcohol maintained between the aforementioned zones as they move through the reservoir from the injection well to the producing well, serious difficulties are encountered.

The presence of large volumes of water in the reservoir hinders the removal of the petroleum by such miscible-phase flooding processes because alcohol dissolves into the reservoir water, deteriorating the alcohol slug. Because of the high solubility of the injected solvent in reservoir water, the leading edge of the solvent zone becomes diluted with water, and the solvent zone may break down entirely, with the result that the oil-to-solvent-to-water miscible-phase displacement is lost. This results in lower oil recovery, or causes high water-to-oil production ratios at the producing well, and increases the alcohol requirement for a given petroleum recovery.

Briefly, this invention teaches a process for the recovery of oil from reservoirs containing high concentrations of reservoir water comprising the steps of first injecting a slug of a gas which is substantially insoluble in the petroleum contained in the reservoir, then injecting a quantity of a solvent which is soluble in both petroleum and floodwater, and finally injecting floodwater to drive the gas and solvent through the formation to a producing well. The purpose of the gas injection prior to the solvent injection is to reduce the water saturation in a large portion of the area which will be contacted by the solvent.

It is an object of this invention to provide an improved method for the secondary recovery of oil from underground reservoirs. Another object of this invention is to provide a method for recovering a higher percentage of the petroleum in reservoirs which contain high concentrations of water.

The injection of gas having a low solubility in petroleum oil prior to the injection of a liquid solvent which is soluble in both the petroleum oil and the subsequently injected floodwater is contrary to principles taught in the prior art. The prior art considers that the injection of a highly mobile gas before the injection of a miscible solvent results in disruption of continuity in the oil phase in the reservoir, tends to result in greater fingering and bypassing of oil-containing zones, and thereby reduces flood efficiency. It has nevertheless been found that where the reservoir to be treated contains water in the amount of about 0.5 pore volume or more, the disrupting effects of the gas injected prior to the miscible solvent is minimized, and the efficiency of the process is enhanced by the reduction in water saturation, the avoidance of loss of solvent into the reservoir water, and by the avoidance

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of dilution of solvent at the leading edge of the solvent-flood front, which would otherwise render the flood ineffective. Accordingly, it has been found that by injecting a gas slug of suitable size prior to the injection of the miscible solvent, when treating reservoirs having a water concentration of not less than about 0.5 pore volume, the efficiency of recovery is raised to a value approximating that obtainable when miscible-phase recovery using the same solvent, in the same amount, is carried out in a reservoir of low water content.

In carrying out the process of this invention, a slug of gas having low solubility in petroleum, in the amount of about 0.1 to 0.5 reservoir pore volume, is first injected through an input well into a petroleum reservoir having an initial reservoir water content of about 0.5 pore volume or greater. The volume of gas injected must be sufficient to substantially displace the formation water and maintain an effective buffer between the formation water and the later-injected solvent. In general, the lowest effective amount of gas will be most suitable, since the injection of a gas slug larger than is required could have an adverse effect upon the sweep efficiency of the process, thereby preventing maximum oil recovery. While quantities of gas in the range of 0.1 to 0.5 pore volume may be employed, in most instances it is preferred to use not more than about 0.2 pore volume of gas, measured at injection temperature and pressure.

A slug of a suitable solvent which is soluble in both petroleum oil and water, and preferably is miscible with both oil and water, is injected into the reservoir behind the first-injected gas. The volume of solvent injected is not critical, but quantities less than 0.03 pore volume are seldom effective, and quantities in excess of about 0.2 pore volume add to the expense of the process without producing a proportionate increase in the oil ultimately recovered. Finally, floodwater is injected in a conventional manner to drive the previously injected gas and solvent slugs towards the producing well. This final water injection is continued until the water-to-oil ratio at the producing well rises to such a level that further oil recovery becomes uneconomical, at which time injection is terminated. This process is applicable to any of the standard flooding patterns, such as the line-drive, five-spot, or nine-spot systems. While not essential, it is preferred that the producing wells be closed in during the period of gas injection, to minimize fingering of the gas through the reservoir and reduce the unfavorable effects of the high mobility of the gas upon sweep efficiency, and further to enhance the effectiveness of the gas in preventing dilution of solvent by reservoir water.

A wide variety of gases are available which may be used in carrying out the process of this invention. The gas chosen must have a solubility in petroleum not greater than about 2% by weight at reservoir temperature and pressure, and should be substantially inert, that is, chemically non-reactive under reservoir conditions. It is also desirable, but not essential, that the gas have a solubility not greater than about 10% by weight in water. Suitable gases include, but are not limited to, nitrogen, flue gas, air, and natural gas which is substantially free of components heavier than ethane. Similarly, a wide variety of materials are available which may be used as the solvent, it being required only that the solvent be liquid in physical state, be capable of dissolving at least about 10% its weight of petroleum, and be soluble in water to the extent of at least 10% of the weight of the water. Preferably the solvent will be miscible with both petroleum oil and water, and still more preferably will have in addition a partition coefficient favoring solution in oil when in the presence of both oil and water. Typical suitable solvents are partially oxidized hydrocarbons such as alcohols, including tert-butanol, sec-butanol, n-butanol,

isopropanol, n-propanol, and pentanols. Other suitable materials include ketones, such as methyl ethyl ketone, diethyl ketone, and di-n-propyl ketone; aldehydes such as acetaldehyde, propanal, and butyraldehyde; and organic acids, such as acetic acid, propionic acid, butyric acid, and isobutyric acid. Mixtures of the aforementioned liquids may also be used in the process of this invention. Mixtures of partially oxidized hydrocarbons produced by hydrocarbon oxidation processes, comprising a wide variety of alcohols, aldehydes, ketones, acids, and other constituents, may be used provided the weighted average of the solubilities of the constituents in petroleum is suitably high. Such mixtures may contain minor amounts of materials having a low solubility in petroleum, such as methyl and ethyl alcohols, provided the quantities of such constituents are not excessive, and other more soluble constituents are present in quantity. Mixtures of C₃ to C₇ alcohols, ketones, aldehydes, and organic acids are suitable.

The effectiveness of the method of this invention has been established by three comparative examples. In each case the core was reconstituted to have an oil saturation of about 0.62 pore volume, and a water saturation of about 0.38 pore volume. In order to obtain high water saturation cores for use in Examples I and III, the cores of these examples were waterflooded to the water and oil saturations stated in these examples. Except as set out in the examples, the test conditions were substantially identical in each case.

Example I

A Berea sandstone core having a water saturation of 0.62 pore volume and an oil saturation of 0.38 pore volume was flooded by first injecting 0.25 pore volume of isopropanol, and then driving the isopropanol through the core by the injection of water. When the water-to-oil ratio in the fluids produced from the core reached a value of 100-to-1, the oil recovery was found to be 31.6% of the oil initially in place, indicating poor efficiency was achieved when the initial water saturation of the core was high. The residual oil remaining after this flood was about 26% pore volume.

Example II

A Berea sandstone core having a water saturation of 0.39 pore volume and an oil saturation of 0.62 pore volume was flooded in a manner substantially identical to that used in Example I. When the water-to-oil ratio reached a value of 100-to-1, the oil recovery was found to be 45.9% of the oil in place, indicating higher flooding efficiency was achieved when the initial water saturation of the core was low.

Example III

In accordance with this invention, a Berea sandstone core containing 0.65 pore volume of water and 0.35 pore volume of oil was flooded by injecting 0.3 pore volume of air, then injecting 0.25 pore volume of isopropanol, and finally driving the isopropanol through the core with water. The conditions of the test were substantially identical with those employed in Examples I and II. At first, the produced fluids consisted almost entirely of water. Thereafter, the water-to-oil ratio rapidly diminished until it reached a very low level. The water-to-oil ratio then again increased, and when it reached a value of about 100-to-1, the total quantity of oil recovery

during operation was found to be 45% of the oil initially in place. This recovery was much higher than that obtained using the same amount of alcohol in treating a high-water-content core (Example I), without the air-injection step. The oil recovery also was as favorable as that obtained when treating a core having a low initial water saturation (Example II) using the same quantity of the same solvent. In each example, the flood was terminated when the water-to-oil ratio in the produced fluids reached a value of 100-to-1. Since the recovery of oil at such excessive water-to-oil ratios is not commercially attractive, the relative efficiency of the processes beyond this point is immaterial.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method for the recovery of petroleum oil from reservoirs containing water in excess of about 0.5 pore volume and petroleum comprising injecting through an input well into said reservoir about 0.1 to 0.2 pore volume of a gas having a solubility in petroleum not greater than about 2% by weight, immediately thereafter injecting about 0.03 to 0.20 pore volume of a liquid solvent capable of dissolving at least about 10% its weight of petroleum and soluble in water to at least the extent of 10% of the weight of the water, driving said solvent through the reservoir by the injection of floodwater, and producing petroleum from an output well.

2. The method in accordance with claim 1 in which the principal constituent of said gas is nitrogen.

3. The method in accordance with claim 2 in which said gas is air.

4. The method in accordance with claim 3 in which said producing well is shut in while air is injected through the input well.

5. The method in accordance with claim 1 in which said liquid solvent consists essentially of oxygenated hydrocarbons having 3 to 7 carbon atoms per molecule.

6. The method in accordance with claim 5 in which said gas is air and the amount of air injected is about 0.1 to 0.2 pore volume.

7. The method in accordance with claim 6 in which the volume of solvent injected is about 0.1 pore volume.

8. A method of recovery of petroleum oil from reservoirs containing water in excess of about 0.5 pore volume and petroleum comprising injecting through an input well and into said reservoir about 0.1 to 0.2 pore volume of a gas having a low solubility in petroleum, immediately, thereafter injecting about 0.03 to 0.20 pore volume of a liquid solvent having a high solubility in water and in petroleum, driving said solvent through the reservoir by the injection of floodwater, and producing petroleum from an output well.

9. A method in accordance with claim 8 in which said producing well is shut in while gas is injected through the input well.

10. A method in accordance with claim 9 in which said gas is air.

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