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METHODS OF RECOVERY OF OIL

Filed July 13, 1950

2 Sheets-Sheet 1

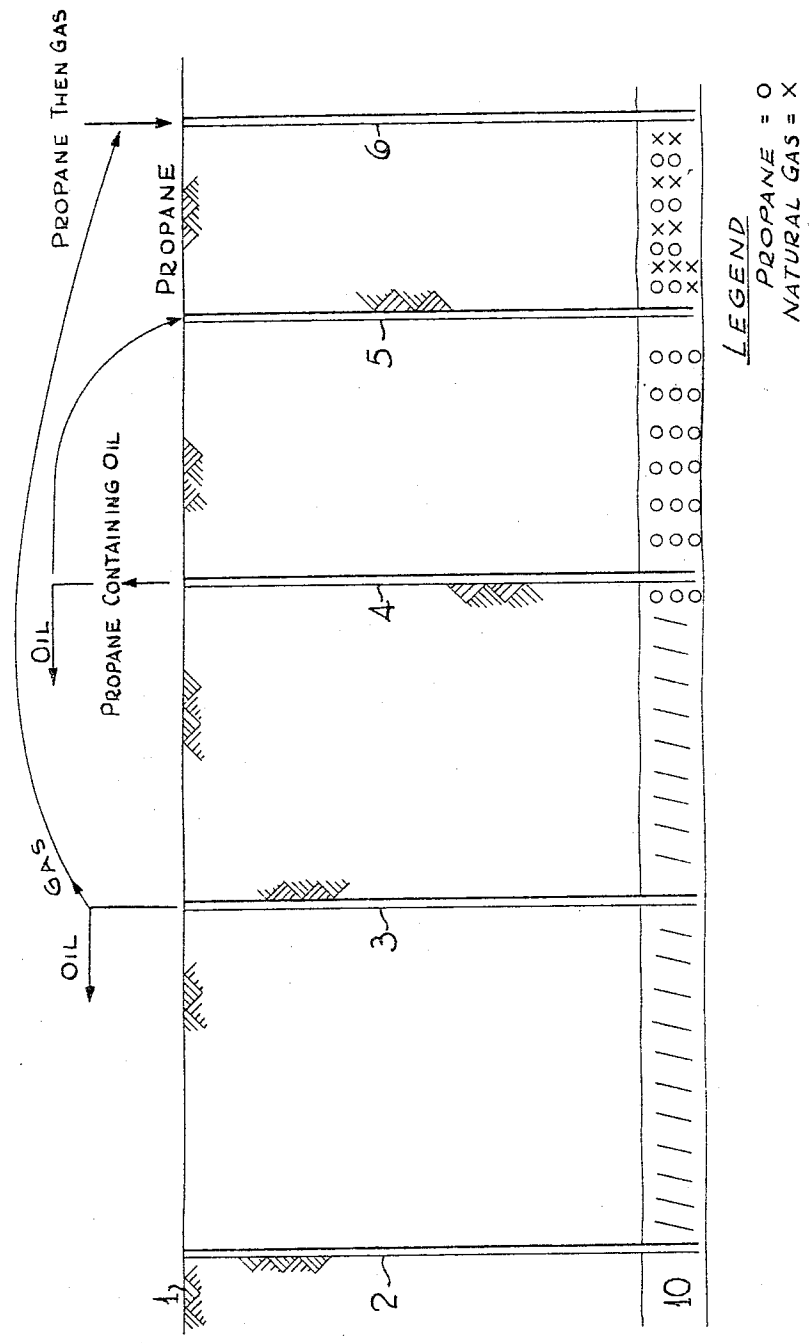


Fig. 1

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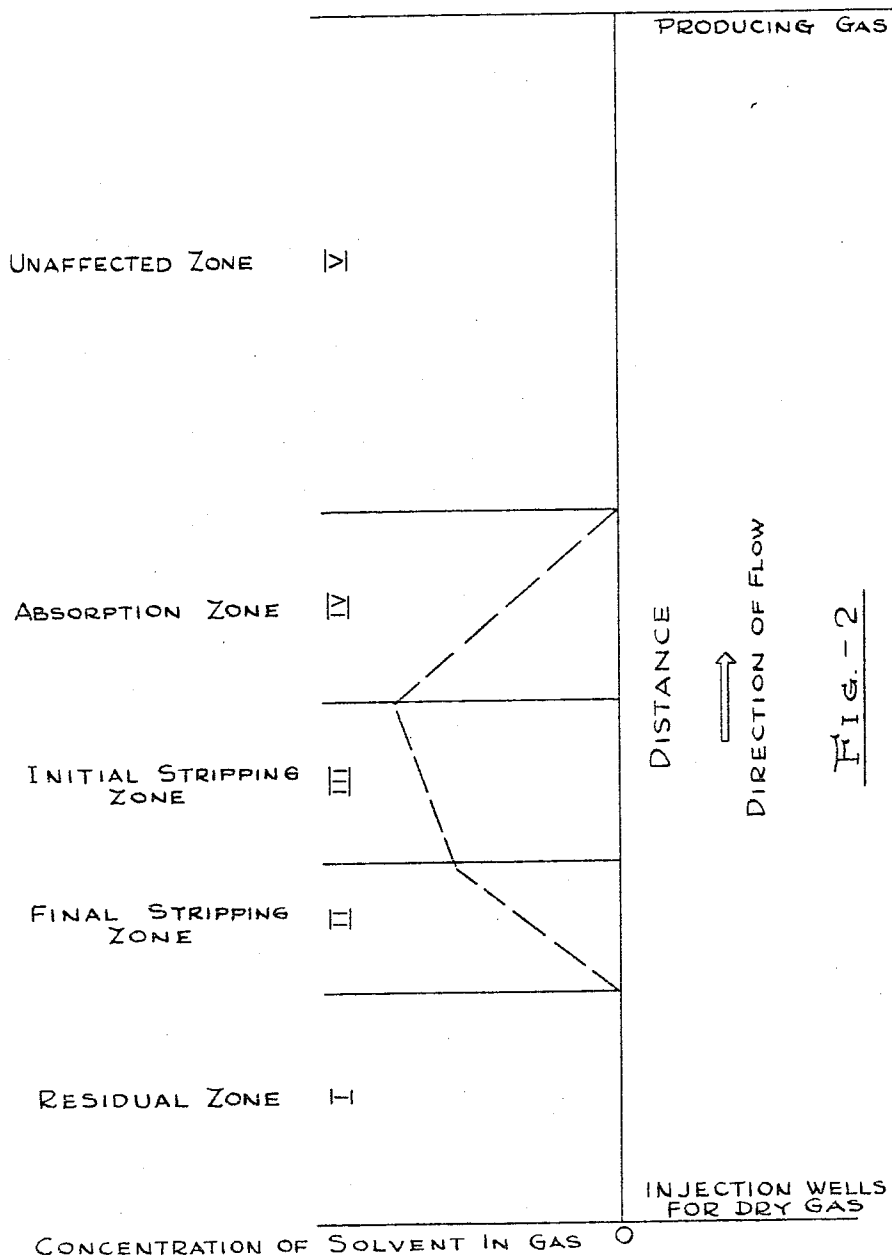
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1

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METHODS OF RECOVERY OF OIL

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The present invention is broadly concerned with an improved method for increasing the production of crude petroleum from oil-bearing formations. The invention is especially concerned with a particular method of utilization of liquefiable solvents, which may be normally gaseous hydrocarbons, for the more complete recovery of oil from subterranean reservoirs. In accordance with the present invention, a quantity of liquefiable solvent which is substantially completely miscible with the crude oil is injected into a reservoir and maintained in a liquid bank of relatively high concentration which effectively washes out the crude oil. The driving pressure of injected gas is utilized to advance the bank of liquid solvent through the reservoirs and essentially complete recovery of the injected solvent is obtained by its vaporization in the recycled gas.

In conventional crude oil-producing operations, situations are frequently encountered wherein oil wells cease to produce at practical rates, even though it is known with certainty that all available, recoverable oil has not been obtained from the field. This diminution in oil production from a given well may be the result of a number of factors. Generally speaking, in fields not subject to an active water drive, the pressure remaining in the particular oil-producing strata may not be sufficient to cause oil to flow toward and into the well bore hole at a practical and economic rate. Thus, the wells of a field tend to become exhausted with respect to primary recovery methods, even when it is known that relatively large quantities of oil are still retained in the reservoirs.

In oil fields characterized by a significant degree of structural relief, it is common practice to extend the active life of the field by maintaining its pressure artificially as by injecting gas into the gas cap of the reservoir or by injecting water into the porous formation at a level below that of the producing wells. In addition, it is commonly known to increase the life of a field beyond the normal limit by secondary recovery methods such as by water flooding, in which water is continuously injected into the producing sand through injection wells and displaces a portion of the residual oil forward into production wells. A similar type of operation may be carried out with gas recycled at low pressure and production increased by this "gas drive" technique. In both of these latter procedures, the motion of the oil forward to producing wells after an initial displacement phase results from the frictional drive of the injected fluids on the residual oil as the injected fluids move from the injection to the producing wells. As a result of these relatively ineffective methods of removing oil from the porous sand, substantial quantities of oil remain behind, even after such secondary recovery operations have in turn reached their economic limits.

The gas and water drives heretofore discussed have generally employed relatively low pressures. More recent proposals for secondary recovery of oil from reservoirs have included the suggestion that gas be recycled at extremely high pressures. Under these conditions, improved recovery of residual oil is obtained because of the increased volume and decreased viscosity of the oil in the reservoir due to solution of components of the gas in the reservoir oil, and due to the increased tendency for vapo-

2

rizization of oil in the high pressure gas. The latter phenomenon is an attribute of operation in the retrograde condensation range in the neighborhood of the critical phase conditions of the reservoir hydrocarbon mixture.

Another procedure is to fill the entire oil reservoir, preferably at increased pressure, with a light hydrocarbon or hydrocarbon mixture or other relatively low viscosity substance soluble in the oil and then to flush out the reservoir with water. In general, it is felt that by this method the injected solute is caused to dissolve in the oil which lessens its viscosity and increases its volume and greatly increases its flowability through the formation. As an alternate to using a single hydrocarbon such as propane alone, the use of natural gas containing light hydrocarbons such as ethane, propane or butane has also been proposed for this purpose. In general, the methods of this type heretofore proposed cause the low-boiling hydrocarbon or equivalent material to dissolve in the oil, thereby reducing its viscosity, increasing its volume and thus permitting increased recovery of the oil by subsequent water flooding. In the present invention, it is proposed to use propane or other readily liquefiable low-boiling hydrocarbon or such other liquefiable substance as possess a substantial degree of miscibility with crude oil such as liquefied carbon dioxide. The operation is carried out in manner such that only a selected section of the oil reservoir at any one time contains any substantial quantity of the added low-boiling hydrocarbon or other equivalent substance. This objective is accomplished by starting at a predetermined point at one section of an oil field and injecting therein a predetermined amount of propane or other selected material. The material is preferably introduced as a liquid but it may be injected as a gas. If it is actually introduced as a gas, reservoir conditions should be such that liquefaction occurs.

The amount of selected material injected should be sufficient to establish a definite band or bank consisting essentially of the injected material in the neighborhood of the injection well or row of injection wells.

The liquid propane or other material is caused to flow through the field to another point or area in the field by a stream of natural gas or of inert gas such as air or combustion products injected after the introduction of the propane. By the process of the present invention, a bank of liquid propane is caused to flow through a selected path in an oil reservoir by a gas stream injected behind the propane. The flowing bank of propane will mingle with the oil contained in the porous formation as it advances through the reservoir, so that the viscosity of the hydrocarbon mixture in the contact zone is appreciably reduced and its movement under the driving action of the gas is greatly facilitated. At the same time, the advancing bank of propane effectively dissolves out the oil which is normally retained in the interstitial spaces of the formation and replaces it with essentially pure propane. The propane being of relatively low viscosity is displaced by the driving gas much more completely than an oil of normal viscosity, and, in addition, the propane not displaced as a liquid by this means is completely vaporized and carried forward by the continued flow of the gas which possessess a substantial carrying capacity for propane vapors.

After the band of propane has moved sufficiently far through the formation, it becomes relatively rich in recovered oil. It is within the scope of the present invention to remove at least a portion of the band of propane containing the dissolved oil at this point; to segregate the recovered oil from the propane and to return the propane to the formation in order to assist in maintaining a liquid bank of concentrated solvent.

Furthermore, the action of the gas driving the propane band on stripping and recovering residual propane from

the depleted portions of the formation, will prevent the retention of appreciable amounts of propane by the already washed portions of the formation. Since the gas will flow more rapidly through the formation than propane or oil, some propane will be carried forward from the bank by the gas stream but this propane in the gas will be absorbed from the gas by the oil ahead of the propane band. By both of these actions the maintenance of a concentrated band of propane is promoted.

It is also within the scope of the present invention to bring the reservoir up to the desired working pressure by conventional means as by injecting natural gas before the injection of the liquefiable solvent, as for example, propane. By operating in the manner proposed, the amount of propane or other selected material employed in the formation at any time may be limited to a very reasonable quantity.

The invention may be more readily understood by the drawings illustrating embodiments of the same:

FIGURE 1 illustrates the invention with respect to the method of flow through an oil reservoir;

FIGURE 2 is a diagrammatic sketch illustrating the five zones which can be anticipated when carrying out the present invention. The concentration of solvent in gas in the respective zones is illustrated by the dotted line.

Referring specifically to FIG. 1, an oil-producing formation 10 is shown disposed below the surface of the earth 1. Well bore holes 2, 3, 4, 5 and 6 are shown extending from the surface of the earth through sub-strata to near the bottom of oil-bearing formation 10. In accordance with one concept of the present invention, a predetermined amount of liquefied propane or an equivalent material is introduced by means of bore hole 6 into the oil-producing sand 10 and is then followed by a continuous injection of a suitable gas into bore hole 6. The band of propane is shown disposed between well bore holes 4 and 5, flowing in the direction of bore holes 3 and 2. Oil is withdrawn from bore holes 2 and 3 together with gas which is separated from the oil at the surface and recycled to injection well 6. Since the band of propane has moved from bore hole 6 to bore hole 4, the front end of the bank contains dissolved therein substantial amounts of oil. Thus, in accordance with one concept of the present invention, a portion of this fluid may be withdrawn from the reservoir by means of bore hole 4. The oil is segregated from the propane by any suitable means such as distillation and passed to suitable storage. The segregated propane is preferably returned to the formation by means of well bore hole 5 immediately back of the band of propane in the formation and ahead of the gas drive.

The gas introduced by means of well 6 serves both to drive the oil and propane bank forward and to remove the residual propane from the oil-depleted zone of the formation by vaporization.

Referring specifically to FIG. 2, the condition of the reservoir is diagrammatically illustrated. After the operation of the present invention has proceeded for some time, it is anticipated that five zones exist. Zone 1 is the residual oil- and propane-depleted zone in which the fluid flowing is chiefly the injected dry gas. Zone 2 is one in which principally residual solvent has been left behind and wherein the solvent is being vaporized and carried forward by the gas stream. The intermediate zone (zone 3) is one in which a band of propane exists which contains in the foremost portion substantial quantities of recovered oil in solution. It is from this zone, and particularly from the foremost portion, that the fluid mixture may be withdrawn to the surface, the oil recovered and the propane returned to the formation, preferably into the rearmost portion of this zone. Zone 4 is one which comprises chiefly oil being forced along ahead of the liquid propane band. This oil zone tends to dissolve out from the driving gas the propane content of

the gas. The final zone is essentially unaffected by the injected solvent. The gas at this point has been practically completely stripped of its solvent and is flowing toward the producing wells through a sand containing oil which has not as yet been mixed with any substantial amount of the solvent.

The present invention is broadly concerned with a novel procedure for the recovery of oil from reservoirs. In accordance with the present process, a band of relatively volatile liquid miscible with oil, as for example, C_3 and C_4 hydrocarbons or carbon dioxide is caused to flow through the formation. This band of liquid is caused to flow by utilizing a gas drive. The gas drive tends to recover from the formation the solvent used to wash out the oil. By operating as described, efficient recovery of the oil is secured through the use of a limited amount of propane or an equivalent solvent. Furthermore, efficient recovery of residual propane from the formation is readily secured.

A specific concept of the present invention is to employ the operation in conjunction with a plurality of spaced bore holes in a particular reservoir. A solvent such as liquefied propane is introduced by means of one bore hole in a sufficient quantity followed by the introduction of gas through the same bore hole. The band or bank of propane is caused to flow through the formation past a second spaced bore hole in the direction of a third spaced bore hole. That portion of the propane bank which has flowed from the first to the third bore hole contains appreciable quantities of recovered oil and can be withdrawn to the surface. The oil is separated from the propane which is preferably returned to the formation by means of the second bore hole, thus interposing the recovered and concentrated propane at a point near the rear of the propane bank and ahead of the gas injection point. The rearmost portion of the propane bank being relatively free of oil constituents will have a very high solvency power and will readily strip the oil formation of the remaining oil constituents. Thus, the band of propane as it flows through the formation by the operation described will have a relatively high quantity of oil in the front end of the pool and be relatively free of oil at the rear end of the moving pool, thus serving to more efficiently remove oil from the formation.

The recovery method of the present invention involves the utilization of a bank of liquid propane or other light hydrocarbons or other miscible material such as CO_2 by passing these liquid substances through producing formations. The solvent can either be introduced as a gas or liquid but the conditions should be such as will result in the formation of a liquid solvent in the reservoir in the form of a bank or band. The bank is driven forward by introduction of natural gas, flue gas, inert gas, air, or combinations of these back of the bank of solvents. The producing formation is subject to a washing action by the bank of propane or other material and, as a consequence, there is little oil left in the formation that has been washed. Some oil may be left due to irregularity in flow due to the fact that producing formations are not homogeneous. The gas flowing back of the bank would have residual liquid, propane, or other material vaporized into it because of the low partial pressure of these materials in the gas. Thus, the liquid propane or other materials being recovered from the formation through this evaporation procedure pass along through the formation with the gas. In accordance with the present invention, the oil is in part recovered from the formation by being increased in volume and reduced in viscosity by dilution with the solvent; but a major contribution to completeness of recovery results from the washing of the sand with the solvent. This washing action is basically countercurrent in nature.

As the propane travels forward, it will drive ahead of it liquid oil which can be recovered as such, with little or no propane in it up to a certain point. Back of a

liquid oil layer will be a layer of a mixture of propane and oil which is preferably also produced, that is, drawn from a well; the propane may then be recovered and cycled back to the formation at a proper point. The gas used to drive the bank of solvent will move faster than the solvent itself, and as a result, it will tend to carry propane as vapor from the propane layer into the oil layer where the propane will be absorbed. This absorption action will tend to prevent excessive widening of the zone of oil-propane mixture.

With respect to specific operating conditions, as for example pressure, they will of necessity depend upon various field conditions as depth of oil-producing formation and temperature of the reservoir. Among other factors controlling operating conditions will be the solvent employed. In general, the practicable, useful control measure will be the pressure of the operation required in order to promote the maintenance of a relatively concentrated band of the solvent material. In general, the pressure should be such as to maintain relatively pure solvent in the liquid condition, which pressure will be at least equivalent to or more generally will be in excess of the vapor pressure of the solvent at the reservoir temperature.

Generally speaking, reservoir temperatures are in the range of from 100° F. to 250° F., although lower reservoir temperatures and higher have at times been incurred. Usual reservoir temperatures are in the range from about 150° F. to 200° F. Under typical reservoir conditions, the vapor pressure of propane will be from about 200 to 600 pounds per square inch, and if propane is employed, pressures of this order or higher may conveniently be employed.

With respect to the rate of recycling of the gas, this quantity will in general be set at the economic optimum which reflects the pressure level, permeability of the formation, separation of the injection and producing wells, etc.

Having described the invention, it is claimed:

1. A method of recovering crude oil from a subterranean oil reservoir through a producing well which comprises the steps of: injecting a normally gaseous solvent into said reservoir through an injection well, said solvent being characterized by a substantial degree of miscibility with oil, said solvent being liquefiable at the temperature of said reservoir and being injected in sufficient amount to establish a bank consisting essentially of said solvent within said reservoir in the neighborhood of said injection well; maintaining a pressure within said reservoir higher than the vapor pressure of said solvent at the temperature of said reservoir during injection of said solvent to establish a liquid bank of said solvent; thereafter injecting into said reservoir through the injection well, at a pressure sufficient to maintain and drive said liquid bank toward said producing well, a normally gaseous drive agent which retains its gaseous state at the temperature and pressure conditions of the reservoir, said liquid solvent being capable of vaporizing into said gaseous drive agent at the pressure and temperature conditions in said reservoir; and withdrawing fluids including said crude oil, said solvent and said gaseous drive agent from said producing well.

2. The process as defined in claim 1 in which said solvent is propane and said pressure maintained within said reservoir is about 200 to 600 pounds per square inch.

3. The process as defined in claim 1 including the step of injecting natural gas into the reservoir prior to the first injection of said solvent in order to bring said reservoir up to the pressure to be maintained within said reservoir.

4. The process as defined in claim 1 in which said drive agent is natural gas.

5. The process as defined in claim 1 in which said solvent is hydrocarbon.

6. The process as defined in claim 1 in which said solvent is propane and said gas drive agent is natural gas.

7. The process as defined in claim 1 in which said solvent is carbon dioxide.

8. The process as defined in claim 1 in which said reservoir is intersected by a third well positioned intermediate and spaced from said producing well and said injection well, said solvent is separated from said withdrawn fluids, and said separated solvent is reintroduced into said bank of solvent through said third well.

9. A method of recovering crude oil from a subterranean oil reservoir through a producing well which comprises the steps of: injecting a normally gaseous solvent into said reservoir through an injection well, said solvent being characterized by a substantial degree of miscibility with oil, said solvent being liquefiable and having a substantial vapor pressure at the temperature of said reservoir and being injected in sufficient amount to establish a bank consisting essentially of said solvent within said reservoir in the neighborhood of said injection well; maintaining a pressure within said reservoir higher than the vapor pressure of said solvent at the temperature of said reservoir during injection of said solvent to establish a liquid bank of said solvent; thereafter injecting into said reservoir through the injection well, at a pressure sufficient to maintain and drive said liquid bank toward said producing well, a normally gaseous drive agent which is normally gaseous at the temperature and pressure conditions of the reservoir, said gaseous drive agent being miscible with said solvent and substantially immiscible with said crude oil; and withdrawing said crude oil from said producing well.

10. A method of recovering crude oil from a subterranean oil reservoir through a producing well which comprises the steps of: injecting normally gaseous hydrocarbons into said reservoir through an injection well, said hydrocarbons being characterized by being liquefiable at the temperature of said reservoir and being injected in sufficient amount to establish a bank consisting essentially of said hydrocarbons within said reservoir in the neighborhood of said injection well; maintaining a pressure within said reservoir higher than the vapor pressure of said hydrocarbons at the temperature of said reservoir during injection of said hydrocarbons to establish a liquid bank of said hydrocarbons; thereafter injecting natural gas into said reservoir through the injection well at a pressure sufficient to maintain and drive said liquid bank toward said producing well; and withdrawing said crude oil from said producing well.

References Cited by the Examiner

UNITED STATES PATENTS

1,978,655	10/1934	Straight	166—21
2,135,319	11/1938	Bays	166—21
2,341,500	2/1944	Detling	166—21
2,347,778	5/1944	Heath	166—21
2,412,765	12/1946	Buddrus et al.	166—21
2,582,148	1/1952	Nelly	166—21
2,669,306	2/1954	Teter et al.	166—21

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