Dec. 10, 1963 D. T. OAKES 3,113,617

SECONDARY RECOVERY TECHNIQUE

Filed Sept. 21, 1960

FIGURE 1

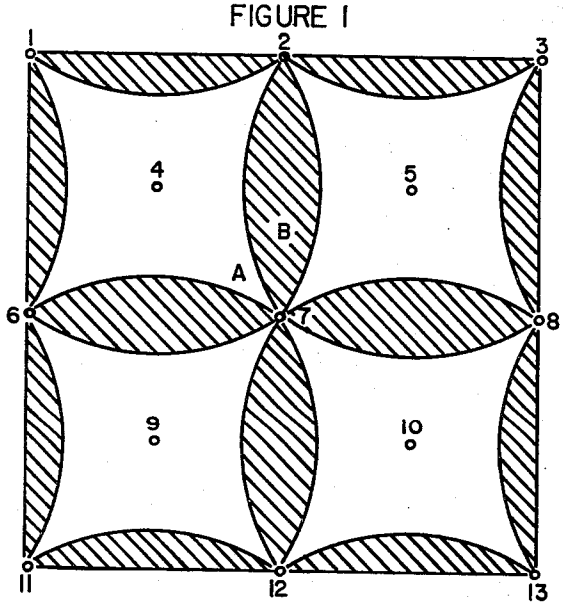
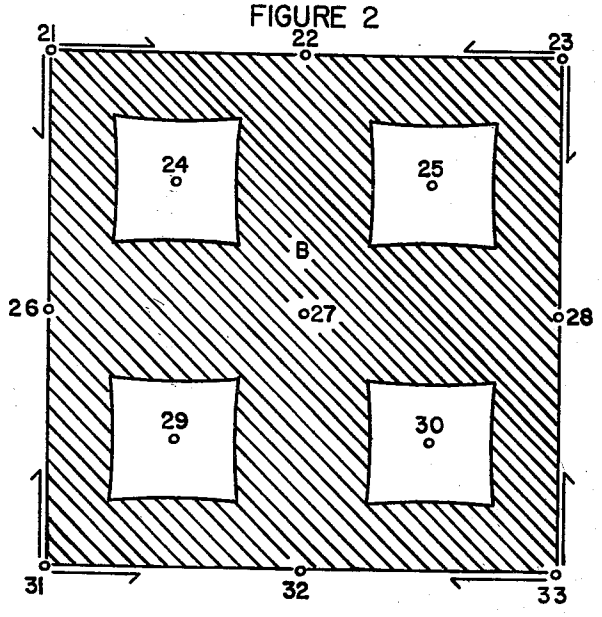


FIGURE 2



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SECONDARY RECOVERY TECHNIQUE

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The present invention relates to a method for increasing the recovery of oil from subterranean petroleum bearing reservoirs. More particularly, the present invention relates to the method for recovering additional oil from subterranean petroleum bearing reservoirs by means of secondary recovery techniques such as water flooding, in situ combustion, propane injection, etc.

During the primary production period of an oil field, oil is produced from the subterranean petroleum bearing reservoir as a result of the natural pressures of the reservoir. These pressures may be sufficient to force oil from the reservoir all the way to the top of the well bore as in so-called flowing wells or they may be only sufficient to displace oil from the reservoir into the bottom of the well bore from where it must be brought to the top by artificial means as pumping. Generally, the natural pressure will eventually decline to the extent that so little oil is displaced from the reservoir that the operation of the producing wells is no longer economically practical. At this point the primary production period may be said to be ended and if additional oil is to be produced from the reservoir, resort must be made to the so-called secondary recovery techniques.

Secondary recovery techniques generally are those methods which supply additional energy to the reservoir for the purpose of moving oil to the producing wells and, in general, tend to recreate the natural pressure or energy originally present in a subterranean petroleum bearing reservoir. These methods generally involve the injection of a gas or liquid into the reservoir and are exemplified by water flooding, CO_2 injection, L.P.G. injection, in situ combustion, etc. Each of the secondary recovery methods has specific advantages and types of reservoir formations and crude oils to which they are particularly adaptable. None of these methods, however, are at present totally efficient in recovering all of the oil remaining after primary production. This problem of incomplete recovery may be understood by considering one of the simplest secondary recovery procedures.

Water flooding secondary recovery is not completely effective in recovering all of the oil which remains within the oil reservoir at termination of the primary production phase of operation. As water is forced into the oil bearing reservoir through an injection well, it spreads throughout the formation in a gradually widening area displacing a bank of oil before it. Initially the water moves out in a roughly circular fashion. However, as the water-oil interface moves further from the injection well and nearer a producing well there is a decrease in the resistance to movement of the water-oil interface toward the producing well. This results in a fingering or cusping of the water front toward the producing well and thereby causes a relatively early breakthrough of the water into the producing well. As a result of this breakthrough of water into the producing well, there is an incomplete sweeping of the oil reservoir by the water flood. After breakthrough, water is produced with the oil. Generally, when the water to oil ratio of the fluids produced from a producing well reaches 50:1 to 100:1 the water flood is discontinued. At this point, which would generally signify the termination of a secondary recovery water flood program, considerable oil still remains in the reservoir. The amount of this oil residue has been estimated to be 30 to 40 percent and higher of the oil initially present in the formation. It has been estimated, also, that water flooding and similar secondary recovery techniques are only effective in removing approximately 50 percent of the oil which remained in the reservoir at termination of the primary production period.

It is, therefore, an object of the present invention to provide a method for increasing the ultimate recovery of oil from oil bearing formations. It is a further object of this invention to provide a method for improving the yields of oil recoverable from subterranean petroleum bearing formations by secondary recovery techniques. A specific object of this invention is to provide a method whereby the yield of oil recoverable by the water flooding method of secondary recovery may be increased. Additional objects will become apparent from the description of the invention herein disclosed.

The aforementioned objectives are fulfilled in a manner which may be best described by reference to the drawings which are a part of this description.

Both FIGURES 1 and 2 present an illustrative plan view of a segment of a multi-well oil field. The numbers 1–13 and 21–33 inclusive indicate wells drilled into a petroleum bearing reservoir. It will be noted that these wells are arranged in a conventional 5-spot arrangement of one well in the center of a square with wells at each corner of the square. This technique of arranging wells is very conveniently employed in secondary recovery programs but is by no means a necessary arrangement to such recovery programs. FIGURE 1, which will be described first, represents the oil field as operated under conventional water flooding techniques. FIGURE 2 will be used to describe the same oil field operated under a water flood program developed in accordance with the present invention. In both figures the wells are, for the purposes of the present description, presumed to be no longer economically attractive to operate under the methods available during the primary production period. Also for the sake of this description, it is to be assumed that this reservoir is one which is particularly suited for the application of a water flood secondary recovery program.

Referring first to FIGURE 1, wells 4, 5, 9 and 10 are to be used as water injection wells. The water flood program is initiated by injecting water into the reservoir through the injection wells, thereby forcing the oil contained in the reservoir outward from the injection wells toward producing wells 1, 2, 3, 6, 7, 8, 11, 12 and 13 through which the oil is withdrawn to the surface. After the water front has moved outward to about midway between the producing wells and the injection well, the front begins to finger or cusp toward the producing wells and at a later time this fingering or cusping projects the water front into the producing wells. Shortly after the entry of water into the producing wells, they can no longer be operated economically. This results in the discontinuance of the water flood project. At this time the oil bearing reservoir will appear as in FIGURE 1. The unshaded portion represents the area swept by the water flood and from which oil has been removed. The portion of the swept area designated A represents the fingering or cusping action of the water flood front. The shaded area B represents the area unaffected by the water flood project. This portion of the reservoir is generally richer in oil than the original reservoir and contains 30 to 40 percent of the oil originally present in the reservoir.

In describing the secondary recovery water flood as applied to the same field in accordance with the present invention, reference will be made to FIGURE 2. Like FIGURE 1 the wells 21, 22, 23, 26, 27, 28, 31, 32 and 33 are producing wells and 24, 25, 29, and 30 are the initial injection wells. Water is injected through the injection wells and thereby oil is driven through the reservoir toward the producing wells through which it is

raised to the surface. This is continued until the water-oil interface lies at a distance from the injection well represented by the line surrounding the unshaded swept area in FIGURE 2. This distance will vary for different reservoir formations and crude oils but may generally be said to represent the distance to which the water-oil interface has moved when 10 to 90 percent of the water normally necessary to cause breakthrough of the water into the producing wells of a given 5-spot arrangement has been injected into the reservoir. When this point is reached, injection through the initial injection wells is ceased or materially reduced. In many cases it is desirable to continue to inject an amount of fluid sufficient to prevent reverse movement of the initial flood front. After shutting-in the injection wells, wells number 21, 23, 27, 31 and 33 are converted from producing wells to injection wells and water passed therethrough into the reservoir. The new injection wells each lie at one end of a potential unswept area if the field were subjected to treatment as in FIGURE 1. By forcing water into these injection wells, the oil which would normally be left in the unswept portions as in FIGURE 1, together with the additional oil which would have been produced under conventional water flood practices, is now forced toward the remaining producing wells 22, 26, 28 and 32 as indicated by the arrows. By this method two advantages are gained. First, the ultimate yield of oil from the reservoir is substantially increased and second, considerably less water is needed per barrel of oil to produce the oil through the more efficient application of the water injected.

To further illustrate the present invention, the following specific example is given. It is to be understood that this example is not in any manner to be construed as limiting the objectives, conditions, operations or application of the present invention.

Two petroleum bearing formations are considered in this example, each 20 acres in size and having a thickness of 20 feet with the same porosity and pore volume. Each contains 5 wells drilled into them with the wells being arranged in a conventional 5-spot configuration as illustrated in FIGURES 1 and 2. Within each of the 20 acre formations is found 400,000 barrels of displaceable oil or 1000 barrels per acre foot. In both formations a water flood secondary project was carried out until a 100:1 ratio of water to oil is obtained in the producing wells. One of the 20 acres formations is subjected to water floor in the following manner. Water is injected into the center well of the 5-spot until there is a breakthrough of water into the producing wells. Injection is further continued until the producing wells reach a water to oil ratio of 100 to 1. The oil recovery is approximately 360,000 barrels and the amount of water utilized is 1,330,000 barrels.

The other 20 acre petroleum bearing formation is subjected to a water floor in accordance with the present invention. Water is injected through the center well of the 5-spot until it is estimated that 50 percent of the water necessary for normal breakthrough into the producing wells has been injected. At this point, injection is stopped through the injection well and it is shut-in and injection initiated in two of the producing wells which are located opposite from one another in the 5-spot arrangement. Water injection is continued through these new injection wells until a 100:1 water to oil ratio is obtained in the two remaining producing wells. The amount of oil recovered in accordance with this application of the present invention is 400,000 barrels. This recovery represents a 100 percent contact and sweeping of the 20 acre area by the injected water. Further, this represents an 11 percent increase in oil recovery over the conventional water flood method employed in the other 20 acre 5-spot. The amount of water necessary for the water flood project of this second 20 acre formation is approximately 1,240,000 barrels or a 7 percent reduction in the amount of water.

The present invention may be summarized as a process for increasing the yield of petroleum through secondary recovery methods wherein water, gas, or other material is injected for the purpose of driving the petroleum contained within the reservoir toward producing wells. The method of the present invention involves the injection of a liquid or gas through an injection well surrounded by a plurality of producing wells until some time prior to the breakthrough of the injected liquid or gas into the producing wells and then shutting-in the initial injection well and thereafter rotating injection to alternate producing wells and withdrawing oil from the remaining producing wells. The point in time at which this rotation of injection takes place is expressed in terms of percent of breakthrough. In most secondary recovery projects the amount of liquid or gas which will have been injected into the petroleum bearing reservoir at breakthrough of the injected liquid or gas into the producing well is known or may be readily calculated. This amount of injection material when injected into the reservoir to the point at which breakthrough into the producing wells occurs would represent 100 percent of breakthrough. The point at which injection is begun in the initial injection well would represent 0 percent of breakthrough. Therefore, rotation at 50 percent of breakthrough would mean a rotation of injection wells at a point in time at which 50 percent of the amount of injection material necessary for breakthrough into the producing wells has been injected. In practicing the present invention rotation should be carried out at 10 to 90 percent of breakthrough with a more efficient and preferred point of rotation being between 20 to 80 percent of breakthrough, with a still more preferred point of rotation being from 40 to 70 percent of breakthrough. It will be understood, of course, that for different reservoir formations the optimum point of rotation expressed as percent of breakthrough will vary.

Since the operability of the present invention is based on the rotation of injection wells at some time relative to the amount of material injected, the injection rates will generally be of no particular importance. Injection may be at any rate suitable for the given formation and the gas or fluid being injected.

Throughout the preceding description of the present invention, reference has been made primarily to the 5-spot arrangement of wells. This was for the purpose of simplification of description and should not be construed as limiting the present invention. The novel secondary recovery technique of this invention may be readily adapted to a 7-spot pattern, a 9-spot pattern, a line drive, a staggered line drive, or to any other pattern or arrangement of wells.

When the initial injection wells are shut-in, it will often be necessary to maintain injection of a very small amount of the injection material in this well. The purpose of this is to maintain sufficient positive force on the original oil-injection material interface that there will be no reversal in direction of this interface due to injection in the new injection wells. The amount of material injected during this period is insignificant as compared to the initial injection rate. This rate of injection will vary considerably with the physical characteristics of the oil bearing formations, injection rates of the new injection wells, and type of secondary recovery method being used, and is therefore obviously not critical. Those skilled in the art will have no difficulty in calculating these injection rates.

Though the present invention finds its greatest applicability in being utilized in water flood secondary recovery programs, it is certainly not limited thereto. It may be equally well utilized with any secondary recovery method wherein liquid or gas injection is necessary. Such other liquids and gases are liquified petroleum gases, pro-

pane, air for in situ combustion, carbon dioxide, carbonated water, etc. In addition to liquids and/or gases, any material classed as a fluid may be utilized. Fluid in its popular sense is considered as referring to liquids and more generally as anything that has fluidity. Herein it is meant to encompass not only these more conventional meanings but also refers to that physical state of a system which may be defined either as a liquid or gas or neither, this frequently occurring where the pressure and/or temperature is greater than the critical pressure and/or temperature of the system. In the event the present invention is used in other secondary recovery methods, certain modifications may become necessary but as such are within the ability of those skilled in the art and having the present disclosure as reference. They may be made and utilized without departing from the spirit and scope of the present invention. The optimum rotation point will vary somewhat as the secondary recovery method varies. However, the ranges of operability will remain within the ranges of rotation points given previously in this specification.

What is claimed is:

1. A method of recovering oil from a multi-well oil bearing reservoir wherein a fluid is injected into the reservoir through a plurality of input wells, each input well being disposed centrally relative to a plurality of adjacent producing wells, and after injection has begun shutting in the injection wells at some time prior to the breakthrough of the injection fluid into the adjacent producing wells and then rotating injection to alternate adjacent producing wells and thereafter withdrawing oil from the remaining adjacent producing wells.

2. A method of recovering oil from a multi-well oil bearing reservoir wherein a fluid is injected into the reservoir through a plurality of input wells, each input well being disposed centrally relative to a plurality of adjacent producing wells, continuing the injection of the fluid until 10 to 90 percent of the volume of the fluid necessary to cause breakthrough of the fluid into the adjacent producing wells has been injected and then rotating injection to alternate adjacent producing wells and thereafter withdrawing oil from the remaining adjacent producing wells.

3. A method of recovering oil from a multi-well oil bearing reservoir wherein a liquid is injected into the reservoir through a plurality of input wells, each input well being disposed centrally relative to a plurality of adjacent producing wells, continuing the injection of the liquid until 10 to 90 percent of the volume of the liquid necessary to cause breakthrough of the liquid into the adjacent producing wells has been injected and then rotating injection to alternate adjacent producing wells and thereafter withdrawing oil from the remaining adjacent producing wells.

4. The process of claim 3 wherein the liquid is water.

5. The process of claim 3 wherein the liquid is selected from the group consisting of liquefied petroleum gases, liquefied carbon dioxide, and carbonated water.

6. The process of claim 3 wherein injection is rotated at a time when 20 to 80 percent of the liquid normally necessary to cause breakthrough of liquid into the producing wells has been injected.

7. A method of recovering oil from a multi-well oil bearing reservoir wherein a gas is injected into the reservoir through a plurality of input wells, each input well being disposed centrally relative to a plurality of adjacent producing wells, continuing the injection of the gas until 10 to 90 percent of the volume of the gas necessary to cause breakthrough of the gas into the adjacent producing wells has been injected and then rotating injection to alternate adjacent producing wells and thereafter withdrawing oil from the remaining adjacent producing wells.

8. The process of claim 7 wherein the injection gas is one selected from the group consisting of carbon dioxide, air, and natural petroleum gases.

9. The process of claim 7 wherein injection is rotated at a time when 20 to 80 percent of the gas normally necessary to cause breakthrough of gas into the producing wells has been injected.

10. In a secondary recovery method of recovering oil from a multi-well oil bearing reservoir in which an injection fluid is injected into a plurality of injection wells, each injection well being surrounded by a plurality of producing wells adjacent thereto from which oil is withdrawn, an improvement comprising shutting-in the original injection wells to an injection rate just sufficient to maintain the minimum pressure necessary to prevent reversal of the injection fluid-oil interface, the original injection wells being shut-in at a time when from 10 to 90 percent of the fluid normally necessary to cause a breakthrough of fluid into the producing wells has been injected into the reservoir and subsequently rotating injection to alternate adjacent producing wells and thereafter withdrawing oil from the remaining producing wells.

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