

Dec. 10, 1963

D. T. OAKES

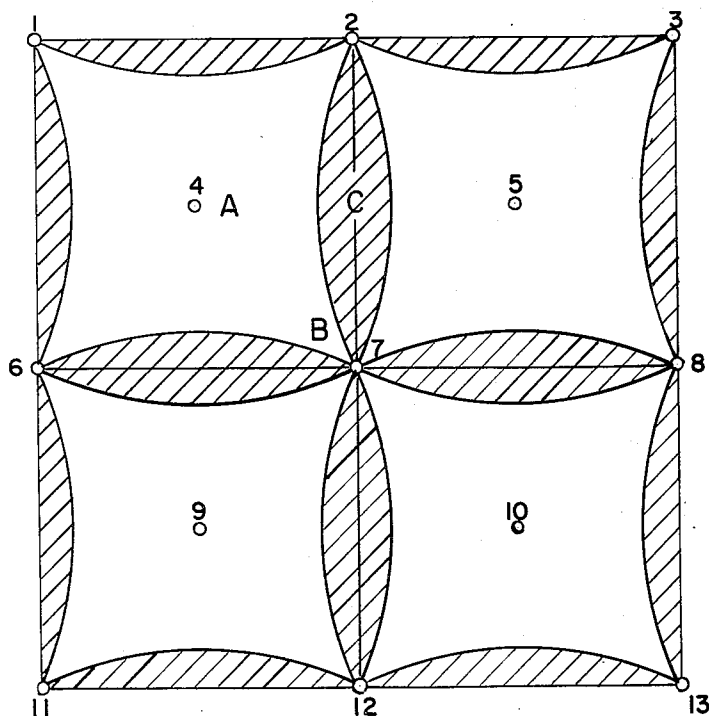
3,113,618

SECONDARY RECOVERY TECHNIQUE

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2 Sheets-Sheet 1

FIGURE 1



DAVID T. OAKES

INVENTOR

BY *M. H. Chas* AGENT

Dec. 10, 1963

D. T. OAKES

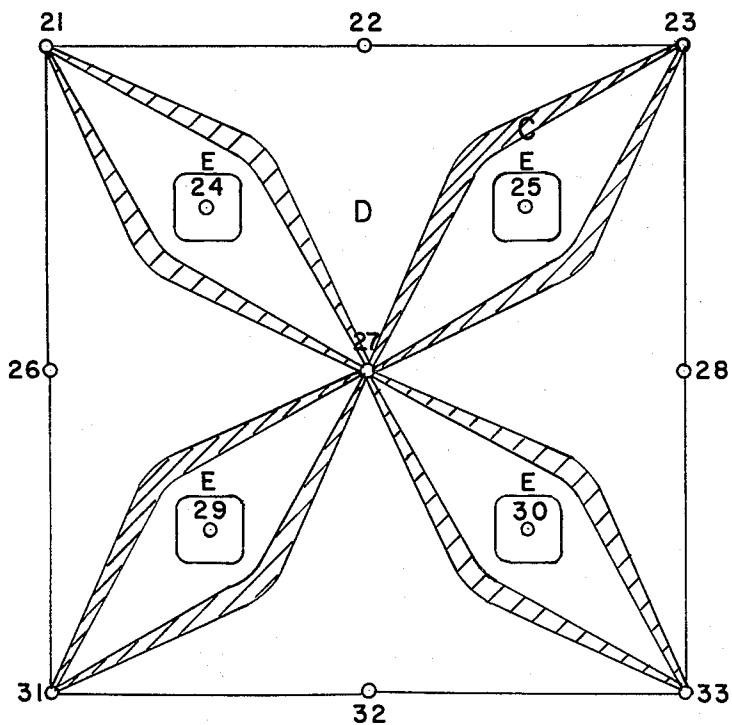
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FIGURE 2



DAVID T. OAKES

INVENTOR

BY *M. A. Gair*

AGENT

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3,113,618

SECONDARY RECOVERY TECHNIQUE

David T. Oakes, Dickinson, Tex., assignor to Monsanto Chemical Company, St. Louis, Mo., a corporation of Delaware

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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 a 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 energy of the fluids in the reservoir. This energy 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 it 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 practicable. 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 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, CO₂ 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 radially from the injection well. 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, oil continues to be recovered, however, 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 per-

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cent 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 indicates 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 A represents the area swept by the water flood and from which oil has been removed. The portion of the swept area designated B represents the fingering or cusping action of the water flood front. The shaded area C 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.

Reference will now be made to FIGURE 2 for the purpose of describing the present invention. In FIGURE 2, the numbers 21, 22, 23, 26, 27, 28, 31, 32 and 33 represent producing wells and 24, 25, 29 and 30 represent the initial injection wells. Initially, water is injected through the injection wells and oil thereby driven through the reservoir toward the surrounding producing wells. This

is continued until the water-oil interface lies at a distance from the injection well represented by the broken line surrounding each injection well. 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 0 to 30% 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. After this amount of water has been injected into the reservoir through the initial injection wells, injection of water through alternate opposing producing wells is begun. In FIGURE 2, these wells are represented by 22, 26, 28 and 32. Injection is maintained in the initial injection wells at a rate sufficient to maintain an outward flow of the water-oil interface through the reservoir. The injection of water in the converted producing wells 22, 26, 28 and 32, is then maintained at a rate sufficient to maintain a ratio of 3:1 to 40:1 between the volume of water injected through each converted producing well and the volume injected through each initial injection well. Thus, in FIGURE 2, if the rate of flow of water into the reservoir through wells 24, 25, 29 and 30 is approximately 50 barrels per day then the volume of water injected into wells 22, 26, 28 and 32 will be approximately 150 to 2,000 barrels per day. The water injection ratio is maintained within the above ratios until there is a breakthrough of water into the remaining producing wells 21, 23, 27, 31 and 33 in such quantities as to render further production economically impracticable. At this time, the reservoir will have the general configuration shown in FIGURE 2 with the unshaded areas representing the area which has been swept free of oil by the water flood. The shaded area represents the small portion of the reservoir which remains unswept by the water flood. This unswept area of FIGURE 2 represents 8 to 12% less of the oil originally present in the reservoir than is represented by the unshaded, unswept area of FIGURE 1.

The advantages to be gained by the present invention are threefold. First the ultimate yield of oil from the reservoir is substantially increased. Second, considerably less water is needed per barrel of oil to produce the oil through the more efficient application of the water injected. A third advantage in the present secondary recovery technique is in its particular adaptability to reservoirs having anisotropic permeability.

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 tracts are considered in this example, each 20 acres in size and having a thickness of 20 feet with the same porosity and pore volume and each surrounded on all sides by comparable tracts being flooded under comparable conditions. Each contains 5 wells drilled into it with the wells being arranged in a conventional 5-spot configuration as illustrated in FIGURES 1 and 2. Within each of the 20 acre tracts is found 400,000 barrels of displaceable oil or 1,000 barrels per acre foot. One of the 20 acre tracts is subjected to water flood 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 100:1. The oil recovery is approximately 360,000 barrels and the amount of water utilized is 1,330,000 barrels.

The other 20 acre tract is subjected to a water flood in accordance with the present invention. Water is injected through the center well of the 5-spot until it is estimated that approximately 5% of the water normally necessary for breakthrough into the producing wells has been injected. At this point, water injection is initiated in two of producing wells located diagonally opposite from one

another in the 5-spot arrangement. The amount of water injected into the converted producing wells is such that its volume is approximately 3 to 10 times that injected in the initial injection well per unit of time. This injection ratio is maintained until there is breakthrough of injection water into the remaining producing wells to the extent of a 100:1 water-to-oil production ratio in these producing wells. The amount of oil so recovered is approximately 400,000 barrels. This recovery represents a 100% contact and sweeping of the 20 acre area by the injected water. This represents a 11.1% increase in 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 1,330,000 barrels or a 10% reduction in the amount of water used per barrel of oil recovered.

The present invention may be summarized as a process for increasing the yield of petroleum through secondary recovery methods wherein a fluid, such as 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 fluid through an injection well surrounded by a plurality of producing wells until an amount of said fluid equivalent to 0 to 30% of that normally necessary to cause breakthrough of said fluid into the producing wells and then initiating and thereafter maintaining injection in alternate producing wells at a rate sufficient to cause a volume ratio of injection fluid injected into the converted producing wells to that injected in the initial injection well of approximately 3:1 to 40:1, said injection in the injection well being maintained at a rate sufficient to produce an outward flow of the oil-injected fluid interface from the injection well through the reservoir and thereafter withdrawing oil from the remaining producing wells.

The point in time at which injection is initiated in the producing wells 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 determined. 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, initiation of injection at 5% of breakthrough would mean initiation of injection in the converted producing wells at a point in time at which 5% of the amount of injection material necessary for breakthrough into the producing wells has been injected into the initial injection well. In practicing the present invention, injection of fluids into the converted producing wells should be carried out at 0 to 30% of breakthrough with a somewhat more efficient and preferred point of time being at some point greater than 0% of breakthrough and 30% of breakthrough. Preferably, injection in the producing wells will be initiated at a point in time when approximately 5 to 15% of a fluid normally necessary to cause breakthrough has been injected into the initial injection well.

In practicing the present invention, it is necessary after injection is initiated in the converted producing wells that a proper volume ratio of injection fluid per unit of time be maintained between that injected in each converted producing well and that injected into the original injection well. This ratio will generally be maintained within the range of 3:1 to 40:1. A somewhat more preferred ratio range is that of 3:1 to 30:1. It is not necessary that the ratio remain constant throughout the secondary recovery operation so long as it remains within the above ranges.

As the present invention is primarily concerned with

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the beginning of injection of an injection fluid into an injection well and subsequently at a defined point in time, initiating injection in alternate producing wells and thereafter maintaining a defined ratio of injection between each converted producing well and the original injection well, the actual injection rates are of no particular importance to the present concept of invention. Injection may be at any rate suitable for the particular formation and the 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.

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 include liquefied petroleum gases, propane, 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.

What is claimed is:

1. 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, the improvement comprising initiating injection of said fluid into alternate producing wells adjacent to said injection wells at a time when from 0 to 30% of the fluid normally necessary to cause a breakthrough of fluid into the producing wells has been injected into the reservoir, the ratio of fluid injected into the alternate producing wells and that injected into the initial injection wells being maintained within the range of 3:1 to 40:1, said injection in the injection well being maintained at a rate sufficient to produce an outward flow of the oil-fluid interface from the injection well through the reservoir, and thereafter withdrawing oil from the remaining producing wells.

2. In a secondary recovery method of recovering oil from a multi-well oil-bearing reservoir in which an injection liquid 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, the improvement comprising initiating injection of said liquid into alternate producing wells adjacent to said injection wells at a time when from 0 to 30% of the liquid normally necessary to cause a breakthrough of liquid into the producing wells has been injected into the reservoir, the ratio of liquid injected into the alternate producing wells and that injected into the initial injection wells being maintained within the range of 3:1 to 40:1, said injection in the injection well being maintained at a rate sufficient to produce an outward flow of the oil-liquid interface from the injection well through the reservoir and thereafter withdrawing oil from the remaining producing wells.

3. The process of claim 2 wherein the injection liquid is water.

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4. The process of claim 2 wherein the injection liquid is selected from the group consisting of liquefied petroleum gases, liquefied carbon dioxide and carbonated water.

5. The process of claim 2 wherein injection is initiated in the producing wells at a time when an amount of liquid greater than 0% but less than 30% of the liquid normally necessary to cause breakthrough of the liquid into the producing wells has been injected into the initial injection well.

6. The process of claim 2 wherein injection is initiated in the producing wells at a time when 5 to 15% of the liquid normally necessary to cause breakthrough of the liquid into the producing wells has been injected into the initial injection well.

7. In a secondary recovery method of recovering oil from a multi-well oil-bearing reservoir in which an injection gas 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, the improvement comprising initiating injection of said gas into alternate producing wells adjacent to said injection wells at a time when from 0 to 30% of the gas normally necessary to cause a breakthrough of gas into the producing wells has been injected into the reservoir, the ratio of gas injected into the alternate producing wells and that injected into the initial injection wells being maintained within the range of 3:1 to 40:1, said injection in the injection well being maintained at a rate sufficient to produce an outward flow of the oil gas interface from the injection well through the reservoir, and thereafter withdrawing oil from the remaining producing wells.

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

9. The process of claim 7 wherein injection is initiated in the producing wells at a time when an amount of gas greater than 0% but less than 30% of the gas normally necessary to cause breakthrough of the gas into the producing well has been injected into the initial injection well.

10. The process of claim 7 wherein injection is initiated in the producing wells at a time when 5 to 15% of the gas normally necessary to cause breakthrough of the liquid into the producing wells has been injected into the initial injection well.

11. 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 0 to 30% of the volume of the fluid necessary to cause breakthrough of the fluid into the adjacent producing wells has been injected and then initiating injection of said fluid into alternate adjacent producing wells at a rate such that the ratio of fluid injected into each producing well to that injected into the input well will be within the range of 3:1 to 40:1 and thereafter maintaining the ratio within this range, the rate of injection into the input wells being sufficient to produce an outward flow of the oil-fluid interface from the injection well through the reservoir and thereafter withdrawing oil from the remaining adjacent producing wells.

12. The method of claim 11 wherein the fluid is liquid selected from the group consisting of water, liquefied petroleum gases, liquefied carbon dioxide and carbonated water.

13. The method of claim 11 wherein the injection fluid is a gas selected from the group consisting of carbon dioxide, air, steam, and natural petroleum gases.

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