FIGURE 1
OIL RECOVERY METHOD USING A NINE-SPOT WELL PATTERN

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Fig. 2

Oil Recovery vs Water Cut

Unconsolidated Sand

\( \mu_o / \mu_w = 4 \times 10 \)

Phase 1

Phase 2

Phase 3

Rotated 5-Spot

Regular 5-Spot

This part of graph enlarged above

OIL RECOVERY % OIL-IN-PLACE

Water Cut %

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OIL RECOVERY METHOD USING A NINE-SPOT WELL PATTERN

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ABSTRACT OF THE DISCLOSURE

A secondary recovery method comprises three phases: first, a grid or network of manifolds is established through the "fingericing" effect resulting from a point-to-point drive to breakthrough using an inefficient sweep technique; second, these manifolds are used as injection areas for water flooding toward additional wells to a time prior to breakthrough; and third, the resulting enlarged manifolds are used as injection areas for water flooding toward still other wells.

Cross reference to related application

This application is a continuation-in-part of U.S. Ser. No. 429,579, filed Feb. 1, 1965, now abandoned.

This invention relates to a method of recovering oil from a subterranean formation. More specifically, this invention relates to an improved method of operating a nine-spot well pattern in secondary and subsequent recoveries to obtain greater oil yields.

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, 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, is 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 cusing of the water front toward the producing well and thereby causes a relatively easy breakthrough of the water into the producing well. As a result of the 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 greater than 40 percent of the oil initially in place 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. Further, although water flooding has been indicated as being relatively ineffective in recovering the remaining oil because of the "fingericing" or "cusing" effect, water, with or without a thickening agent, is the most efficient single-step method of the known secondary recovery techniques so far as obtaining an areal rather than a lineal sweep pattern; other techniques, e.g. miscible flooding, in-situ combustion, or immiscible gas sweep, are all more prone than water to "finger" or "cusp".

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.

FIGURE 1 is a representative of a plan view of wells in the so-called nine-spot pattern, while FIGURES 2 and 3 are graphical representations of oil recovery obtainable by practice of a prior-art method and by the method of this invention.

This invention comprises effecting secondary or subsequent recoveries by what might be called a rotated five-spot method. According to the invention, there is provided broadly a method which comprises sequentially establishing one grid of "fingers" or channels communicating between wells in a nine-spot pattern, establishing an incomplete second grid of fingers substantially at 45 degrees rotation from the first grid in plan view, and then completing recovery by sweeping from one of the grids to the other.

Referring now to FIGURE 1, there are shown twenty-five wells laid out in a regular grid; the central nine of these wells comprise one nine-spot pattern, which can be repeated in array, as known in the art. The method of this invention comprises three distinct phases, which can be stated broadly as establishing channels or fingers conforming to either the grid represented by the solid lines or the grid represented by the broken lines by use of an inefficient secondary recovery technique in a first phase, establishing incomplete fingers conforming in direction to the remaining grid by water flooding in a second phase, and sweeping from one of the grids to the other by water flooding in a third phase.

When a flood is conducted in a field where the flood...
fluid is more mobile than the reservoir oil, flood fluid will normally tend to shoot a so-called "finger" to its producing well. This means the flood fluid "finger" will reach the producing well in the reservoir almost as fast as it is swept by the flood fluid. In one of its embodiments, this invention can modify the flood plan in such a way that the areas least affected by the flood fluid during normal operations will be efficiently flooded during a second phase of our method. Another embodiment of our invention is suited for practices in those fields where the oil is of relatively low viscosity.

It can be seen in FIGURE 1 that the nine wells in the center form a nine-spot pattern in which the center well is labeled B, the four corner wells are labeled C, and the four additional wells which are midway on the sides between the corners B are labeled A. In an infinite array of wells in such a pattern, the distribution of wells is 50% A, 25% B and 25% C. One of the novel features in our invention resides in the fact that certain of these wells are temporarily shut in during certain phases of the practice of our invention, and in spite of this or because of it, very high recovery efficiency is obtained.

Considering first the embodiment of the invention which is peculiarly adapted to fields in which relatively viscous oil is present, it can be stated broadly that the first phase of the invention has as its objective the establishment of "pumping fingers" in such fields as represented by the broken-line grid, while the second phase incompletely establishes the solid-line grid. In the first phase only wells B and C are used. Drilling and completion of wells for locations A can be delayed until the end of phase 1. Wells C are injection wells and wells B are producers during phase 1. Thus, this well arrangement during phase 1 is that of an ordinary "5-spot." The first phase is affected by an "inefficient" secondary recovery technique, e.g. miscible flooding, in-situ combustion, or immiscible gas sweep, and proceeds to breakthrough or until a moderate to high production of flood fluid is obtained at the producing wells in the event of miscible flooding. This amounts to a flood fluid cut of 1 to 80 percent of total fluids produced at the producing well. The lower cut is obtained in uniform formations and the higher cut in very nonuniform formations, such as fractured limestones.

In the event that the gas sweep is used for the first phase, gas injection should be preferably continued beyond breakthrough until a relatively low gas-oil ratio of perhaps 2000 s.c.f. bbl. is reached. In the second phase, all injection wells C used in the first phase are temporarily shut in. The producing wells B are converted to water injection wells. New producing wells A are placed on production in the "in-fill" well locations of the original five-spot, as shown in FIGURE 1. The arrangement during the second phase of this flood in effect causes a 135° change in the flow direction of the shortest stream line between injection and producing wells. This change in direction causes an efficient sweep of the oil lying in the region of the reservoir that was least affected by the flood fluid during the first stage of the flood. The second phase of the flood is continued until water injected equals about 50 to about 300 percent, preferably about 50 to about 75 percent, of oil produced during phase 1. Again, the termination point depends on the uniformity or nonuniformity of the reservoir. Thus, the second phase is terminated at the lower percentage of around 50 percent in a uniform reservoir and at the higher percentage of around 75 percent to 300 percent in a highly nonuniform reservoir. The second phase is followed by a third and final phase, wherein the temporarily shut-in injection wells C of the first phase are opened again and used along with the second-phase injection wells B as water injection wells, and is continued to a high water cut generally called the economic limit, i.e., the point at which it becomes unprofitable to continue the flood. It can be seen from the preceding that, during the second phase of this embodiment, there are twice as many producing wells A as there are injection wells B, which is advantageous in that the producing wells are considered to be the bottleneck when operating on viscous oil.

In the second embodiment of the invention, which is more suited to operation in a field of low viscosity oil, the first phase is similar to that described in the preceding paragraph, except that wells A and B are utilized to establish fingers conforming to the solid-line grid of FIGURE 1. However, in the second phase wells B are used for injection and wells C are used for producing, while wells A are temporarily shut-in. In this embodiment, there is a 2:1 ratio of injection to production wells during the first phase, and a 3:1 ratio during the third phase, which is advantageous for low viscosity crude in that the injection fluid rate is generally considered to be the limiting factor in that situation. The third phase of this embodiment is similar to that of the preceding one, except that a sweep is effected from wells A plus B to wells C.

Two additional embodiments can be explained readily by simply noting that the first phase of the two preceding embodiments establishes the fingers comprising respectively the broken-line and the solid-line grid of FIGURE 1, while the second phase partially establishes the solid-line and the broken-line grid, effecting a change in flow direction of 135° between phases. It is obvious that the direction of establishing these two grids can be reversed relative to each other. Two embodiments are within this order of phases in that the ratio of injecting to producing wells in phase 3 can be either 1:0 or 3:1, and is so chosen depending primarily upon the mobility of the oil. However, the first embodiment of two paragraphs back is existing field in the 5-spot pattern, simply because phase 1 of that embodiment requires only wells B and C which are the assumedly-existing 5-spot pattern, and thus the investment in wells A can be deferred until required for phase 2, and because of the change in flow direction effected therein.

These four embodiments can be presented in tabular form as follows:

<table>
<thead>
<tr>
<th>Embodiment</th>
<th>Phase</th>
<th>Injecting</th>
<th>Producing</th>
<th>Shut-In</th>
<th>Ratio: Injecting:Producing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>C</td>
<td>B</td>
<td>A</td>
<td>1:1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>1:1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>1:1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>1:1</td>
</tr>
</tbody>
</table>

The invention will be further illustrated by the following examples.

**EXAMPLE 1**

This example compares the first embodiment of the "rotated 5-spot" method of this invention with the conventional 5-spot recovery method.

Laboratory tests on unconsolidated sand have shown that the method of this invention produces more oil per unit injection water than is possible by a conventional five-spot flood. The sand used in this model test was clean Ottawa sand of the following size distribution:

<table>
<thead>
<tr>
<th>Screen Microns</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2,000</td>
</tr>
<tr>
<td>80</td>
<td>1,500</td>
</tr>
<tr>
<td>180</td>
<td>1,255</td>
</tr>
<tr>
<td>270</td>
<td>88</td>
</tr>
</tbody>
</table>

Distilled water and a refined oil with a viscosity of 438 centipoises at 75° F. was used. The oil was a blend of 400 pale oil and bright stock. The sand was packed in a model shaped as indicated in FIGURE 1. Dimensions were eight inches along the sides AC and AB. Thickness was one-half inch. Sand was packed tightly into this model.
resulting in a porosity of 34.2 percent. The sand was packed in water, then flooded with oil, and finally flooded with water. First, a regular 5-spot flood was performed using wells C and B as injection wells and A as producing well. A new sand pack was then prepared and a "rotated 5-spot" flood was performed, in which well C was an injection well and B a producing well. In the first phase, B an injection well and A a producing well in the second phase, and B and C injection wells and A a producing well in the third phase.

Phase 1 was terminated at water breakthrough. The choice of the terminating point used in the laboratory was based on the field phenomenon point for field conditions. The reason for the difference lies in the fact that the permeability characteristics of the laboratory model are much more uniform than can be found in actual reservoirs in the field. An actual reservoir is generally composed of a variety of earth layers, strata or lenses of widely varying permeability. The terminating point of phase 1 for field conditions comprises a point at which water has broken through in approximately half of the layers, strata or lenses exposed in the producing well.

Results of these tests are shown in FIGURES 2 and 3. FIGURE 2 shows that the rotated 5-spot flood recovered more oil at any water cut ranging from 0 to 98 percent of total produced fluid than the regular 5-spot flood. FIGURE 3 shows that during the second and third phases of the rotated 5-spot flood, more oil was recovered per unit of water injected than in the comparative phases of the regular 5-spot flood.

EXAMPLES 2-4

Emibodiments 2, 3 and 4 from the above table are carried out in sand tables similar to those of Example 1, and overall recoveries in each instance are similar to those obtained by the "rotated 5-spot" in Example 1.

EXAMPLES 5-10

Slabs of sandstone from Berea outcrop in Ohio were prepared to the dimensions 2 ft. x 2 ft. x 2 inches; they had an average porosity of 20% and an average S_w of 25%. Holes of 1/4" diameter were drilled through the slabs near each corner and at the center. The slabs were saturated with 30,000 p.p.m. NaCl brine and then reduced to an irreducible water saturation by flooding with a refined 550 cp oil. The gas used in phase 1 of runs 9 and 10 was nitrogen, and injection pressures of both gas and water were 300 p.s.i.g. Outlet pressures were 0 p.s.i.g.

From the following runs, it can be seen that normal water floods were reasonably reproducible and that combined gas and rotated water floods according to the present invention yielded substantially higher recoveries than unrotated water floods. The runs are summarized in the following table.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>k, md</th>
<th>O.I.I.P.</th>
<th>Bbl. water injected/ bbl. oil produced</th>
<th>S.c.f. gas injected/ bbl. oil</th>
<th>Oil recovery percent</th>
<th>O.I.I.P.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal water flood (no gas injection)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>79</td>
<td>1,000</td>
<td>5.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>145</td>
<td>1,000</td>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>212</td>
<td>1,000</td>
<td>6.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>409</td>
<td>1,000</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>619</td>
<td>1,000</td>
<td>7.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas injection followed by pattern rotation water flood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>409</td>
<td>1,500</td>
<td>6.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>819</td>
<td>1,500</td>
<td>6.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Compared to oil recovery by normal water flooding.

As discussed earlier herein, the termination of the first and second phases of this invention can be varied from one situation to another, but the main objective is to form the grid in a manifold, and better ultimate recoveries are obtained when phase is well in the first phase, through of the fingers forming the first grid. The first phase is preferably terminated at a fluid cut of about 10 to 40 percent of total liquids at the producing well, while the second phase should be terminated at an earlier stage, i.e. until water injected equals about 50 to about 300 percent of oil produced during phase 1, preferably about 50 to about 100 percent. Equivalent termination times are used when operating with a recovery fluid other than water.

The art is replete with various combinations of secondary recovery techniques, such as fire flooding followed by water flooding, and it is obvious that such combinations can be adapted to the method of this invention. The presently preferred combination, however, comprises an "efficient" drive in the first phase, followed by water flood in the second and third phases.

Having thus described the invention by providing specific examples thereof, it is to be understood that no undue limitations or restrictions are to be drawn by reason there-of and that many variations and modifications are within the scope of the invention.

We claim:

1. The method of improving oil recovery by sweeping a subterranean oil-bearing formation penetrated by a plurality of wells in a 9-spot pattern which comprises:
   (a) passing a recovery fluid other than water into said formation by way of one group of wells selected from the group consisting of central, corner, and additional wells of said 9-spot pattern while concurrently maintaining open to allow producing therefrom another of said groups and maintaining in a temporarily shut-in condition the third of said groups, said third being selected from said corner and said additional wells, the groups of said passing and said maintaining being selected so as to establish upon breakthrough a grid of fingers in said formation oriented in a manner with respect to said pattern selected from the group consisting of including said central and said corner wells and including said central and said additional wells,
   (b) continuing said passing and said maintaining of step (a) until at least such time as breakthrough of said recovery fluid is achieved in said another of said groups,
   (c) subsequently temporarily shutting in one of said groups of wells comprising said corner or said additional wells not selected as said third in step (a) while concurrently passing water into said formation by way of said central wells and maintaining open for production the remaining group of said wells, said passing being continued until the amount of water injected equals about 50 to about 300 percent in volume of the amount of oil recovered during steps (a) and (b), and
   (d) subsequently recovering oil from said formation by way of the group of wells maintained open for production in step (c) while concurrently passing water into said formation by way of the remaining two of said groups.

2. The method of claim 1 wherein said remaining wells are drilled at a time subsequent to initiation of step (a).

3. The method of improving oil recovery by sweeping a subterranean oil-bearing formation penetrated by a plurality of wells in a 5-spot pattern which comprises:
   (a) passing a recovery fluid other than water through said formation by way of the corner wells of said pattern while concurrently maintaining the central well of said pattern open to allow producing therefrom until at least such time as breakthrough of said recovery fluid is achieved in said central well,
   (b) subsequently opening to communication with said formation additional wells intermediate said corner wells so as to effect a 9-spot pattern by the summation of said corner, central, and optional additional wells, and
   (c) subsequently temporarily shutting in said corner wells while concurrently passing water into said
formation by way of said central wells and maintaining open for production said additional wells until such time as a predetermined finite amount of said water is introduced by way of said central wells, and then
(d) subsequently passing water into said formation by way of said central plus said corner wells while concurrently maintaining said additional wells open to allow production therefrom.

4. The method of claim 3 wherein said predetermined amount in step (c) is between about 50 and about 75 percent by volume of the oil recovered in step (a).

5. The method of claim 3 wherein said recovery fluid comprises gaseous product of in situ combustion in said formation.

6. The method of claim 3 wherein said recovery fluid comprises a gas substantially immiscible with oil.

7. The method of claim 3 wherein said water contains a thickening agent.

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<th>Inventor</th>
<th>Class</th>
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<td>Jenks</td>
<td>166—9</td>
</tr>
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<td>12/1963</td>
<td>Oakes</td>
<td>166—9</td>
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<tr>
<td>3,113,618</td>
<td>12/1963</td>
<td>Oakes</td>
<td>166—9</td>
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<td>166—9</td>
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<td>166—9</td>
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