

Sept. 6, 1966

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3,270,809

MISCIBLE DISPLACEMENT PROCEDURE USING A WATER BANK

Filed Sept. 11. 1963

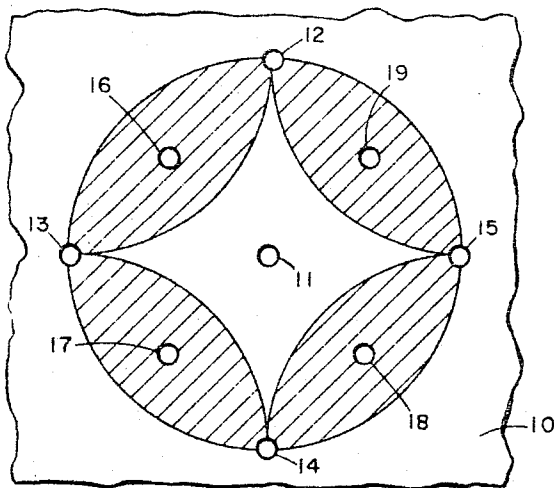


FIG 1

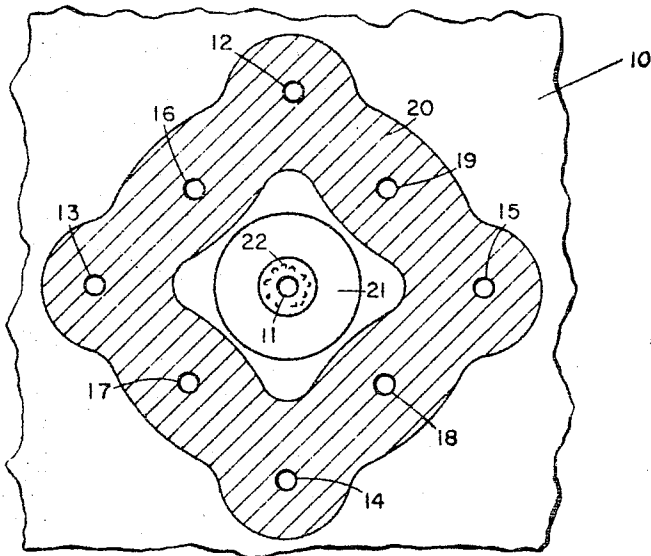


FIG 2

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1

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MISCIBLE DISPLACEMENT PROCEDURE USING A WATER BANK

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Filed Sept. 11, 1963, Ser. No. 308,162

13 Claims. (Cl. 166-9)

This invention relates to the recovery of crude oil from subterranean reservoirs by miscible displacement procedures. More particularly, it relates to the use of a water bank to facilitate miscible displacement procedures for recovering crude oil.

Various miscible displacement procedures for recovering crude oil from subterranean reservoirs are known. The term "crude oil," as it is used herein, refers to the hydrocarbonous formation fluids present in reservoirs. Connate water may be present in the reservoir and does not interfere with the present miscible displacement procedure. Such procedures usually are utilized when the natural reservoir forces are of a magnitude insufficient to produce the crude oil residing in the reservoir within imposed economic limitations. Usually, these procedures require the injection of a miscible fluid, such as propane, or liquefied petroleum gas, into the reservoir. Hereinafter, the liquefied petroleum gas will be designated as LPG. Preferably, the miscible fluid is injected in a slug of a sufficient volume so that it will travel as an expanding annular ring through the reservoir displacing the crude oil before it. For such purposes, a driving fluid, usually a noncondensing gas, is injected behind the slug of miscible fluid to drive it through the reservoir. The noncondensing gas is usually injected at a pressure sufficient to achieve the miscibility required between the slug of miscible fluid and the in situ crude oil for efficient operation of the miscible displacement procedure. The miscible fluid and the driving fluid function may be provided by a unitary fluid such as enriched natural gas, or natural gas at the reservoir critical or convergence pressures. The term "miscible displacement fluid" is used hereinafter to functionally identify the unitary fluid and also the miscible fluid and driving fluid. In some reservoirs, the characteristics of the formations, including permeability, are such that sufficient pressure for miscibility cannot be obtained without injecting excessive amounts of the miscible displacement fluid. It is widely known in the art to increase the pressure of the miscible displacement fluid used to displace the in situ crude oil by restricting fluid flows in the reservoir. One means to accomplish this result is to inject a bank of water in front of the miscible displacement fluid to at least partially plug the reservoir. For example, the water is injected in an amount to form a bank of sufficient mass to produce a desired primary reduction in fluid permeability in the reservoir. The bank of water may also have sufficient mass to be maintained between the in situ crude oil and the miscible displacement fluid throughout the extent of radial traverse of the bank of water through the reservoir. Under such circumstances, the water not only forms a restriction to fluid flow in the reservoir, but also increases the areal sweep efficiency and improves the invasion efficiency of the miscible displacement fluid. The water to provide the bank of water generally is injected through each well used to inject the miscible displacement fluid. Using several injection wells will decrease the time period required to form the bank of water. However, this is not an efficient use of the wells since it provides an unused excess of injection capacity for the later injection of the miscible driving fluid.

The problem of forming the water bank is greatly

2

accentuated whenever the reservoir requires large quantities of water to obtain the reduction of fluid flows traversing the reservoir to allow the necessary miscibility pressure to be secured. The creation of the water bank is also more difficult where "thickeners" are used in the water to increase its viscosity. Even in reservoirs having high in situ pressures, the amount of water required to provide a water bank capable of sustaining itself ahead of the miscible displacement fluid to improve volumetric sweep efficiency requires an excessive, uneconomical length of time to inject.

It is a primary object of this invention to provide a method for creating a water bank preparatory to a miscible displacement procedure without the disadvantages obtained by the injection of water in each well later to be used to inject the miscible displacement fluid. Another object is to provide for the injection of a water bank into a reservoir in a more economical manner than in the past. Yet another object is to create a water bank in a reservoir to increase reservoir pressure in the region of the water bank, to selectively reduce the permeability to hydrocarbon miscible fluids in the more permeable zones, and to increase the volumetric sweep efficiency of hydrocarbon miscible fluids by injecting water into the reservoir in a novel manner. Another further object is to provide a method for establishing a bank of water in a reservoir to obtain the desired stated advantages with miscible displacement procedures in reservoirs penetrated by a random arrangement of wells and by a plurality of wells arranged in a regular and uniform geometric pattern. These and other objects will become more apparent when considered in conjunction with the following detailed description, the appended claims, and the attached drawings wherein:

FIGURE 1 illustrates a conventional "9-spot" well pattern disposed in the earth after the initial steps of the method of the present invention have been applied to provide a bank of water in an oil-bearing reservoir; and

FIGURE 2 illustrates the structure of FIGURE 1 upon completion of the steps of the present method in such pattern and initiating a miscible displacement procedure.

The drawings illustrate only a portion of the reservoir, and it is to be understood that the "9-spot" well pattern shown in FIGURES 1 and 2 is merely a part of a repeating "9-spot" regular and uniform geometric pattern of wells which penetrate the reservoir.

The objects of the present invention are achieved by a method for recovering oil from a subterranean oil-bearing reservoir penetrated by a plurality of wells. As a first step, a continuous bank of water is formed in the reservoir in spaced relationship about a central well by injecting water into the reservoir through a plurality of surrounding wells. The water may contain any additive such as "thickeners," if desired. The wells used for the injection of water may be closed off when the bank of water is completed. As the water is injected into the reservoir, in situ crude oil may be produced from the reservoir through wells other than the wells being used for injecting the bank of water. After the formation of the bank of water, miscible displacement fluid is injected through the central well into the reservoir behind the bank of water. Thereafter, the miscible displacement fluid is driven radially outwardly through the reservoir from the central well and crude oil is produced from the wells in the reservoir surrounding the bank of water. As will be apparent hereafter, several additional steps and modifications of the listed steps may be taken to achieve even greater improved results through the method of using a water bank in miscible displacement procedures for the recovery of crude oil from subterranean reservoirs.

Referring first to FIGURE 1 of the drawings, there is shown a well pattern unit of a conventional "9-spot"

pattern of wells penetrating the reservoir 10, which pattern is commonly used in miscible displacement procedures for the recovery of crude oil. The wells are in a regular and uniform geometric disposition in the reservoir 10. In the pattern, there is a central well 11 surrounded by equally spaced wells 12, 13, 14, and 15 at one radial dimension therefrom and equally spaced wells 16, 17, 18, and 19 at a somewhat lesser radial dimension from the central well 11. For the purposes of this description, it may be considered that the wells 12, 13, and 16 and 14, 15, and 18 are aligned in rows next adjacent to the well 11; whereas the wells 12, 15, and 19, and 13, 14, and 17 are aligned in lines next adjacent to the well 11. The "9-spot" pattern repeats itself throughout the reservoir, but such wells are not shown in FIGURE 1. The method of this invention is not limited to a "9-spot" pattern, or any other regular and uniform geometric patterns but may be used with irregularly disposed wells, as will be apparent from the following description. The reservoir 10, for purposes of this invention, may be considered to be uniformly isotropic, both horizontally and vertically, in its fluid-flowing characteristics. Also, the reservoir 10 has such characteristics that miscibility pressure is not readily obtained. However, it will be apparent hereinafter that the present invention may be applied to reservoirs having uniform and irregular anisotropic fluid flowing capacities in both the horizontal and vertical planes.

As the first step, water is injected into the reservoir 10 about the central well 11 through a plurality of surrounding wells to form a continuous bank of water in spaced relationship about the central well 11. For example, water can be injected through the wells 16, 17, 18, and 19 into the reservoir 10. The water is injected at a suitable rate where the injection pressure does not exceed the overburden breakdown pressure of the reservoir 10. Contemporaneously, the in situ crude oil displaced by the injected water is produced from the wells 12, 13, 14, and 15 by any suitable means as will be apparent to those skilled in the art. Also at such time, crude oil may be produced from the central well 11 and also the wells surrounding the well pattern unit shown in FIGURE 1, if desired. Of course, more water is injected than crude oil produced with respect to the reservoir so as to effect an increase in reservoir pressure in the regions about the wells 16, 17, 18, and 19. Where the conditions of the reservoir 10 warrant, the injection rates of water into the wells 16, 17, 18, and 19, and the rates of production of crude oil from the wells 12, 13, 14, and 15, along with the rates of production of crude oil from other wells in the reservoir 10, may be adjusted so as to produce a flow of water between the wells 16, 17, 18, and 19 to the wells 12, 13, 14, and 15. Reference may be had to U.S. Letters Patent 2,347,778 for such means to direct the flow of fluids in subterranean formations. When the water breaks through at the wells 12, 13, 14, and 15, the wells 16, 17, 18, and 19 may be closed off.

Referring to FIGURE 2, water is injected into the formation 10 through the remaining wells 12, 13, 14, and 15 until a continuous water bank 20 is formed in the reservoir 10 in spaced relationship about the central well 11. Thereafter, the wells 12, 13, 14, and 15 may be closed off. During the formation of the continuous water bank 20, crude oil is produced from one or more wells in the reservoir 10 other than the wells used for the injection of water. For example, crude oil may be produced from the reservoir 10 through the central well 11 and also, if desired, through the wells surrounding the water bank 20. The conditions of water injection and oil production may be the same, or similar, as during the injection of water through the wells 16, 17, 18, and 19 to secure the fluid flows to form the water bank 20.

As previously mentioned, the amount of water, and the use of additives, in the water bank 20 depends on the desired effect on the characteristics of the reservoir 10 and the miscible displacement procedure to be used. In

some cases, only an amount of water need be used to obtain a sufficient increase in reservoir pressure whereby miscibility pressure is obtained. In other cases, the amount of water should be sufficient to maintain the water bank 20 over the entire reservoir 10 to be traversed. The amounts of water to be injected are readily determined from the ultimate result desired by artisans skilled in this art.

Thus, by the steps of the present invention, there is formed a water bank 20 by the injection of suitable quantities of water at a much accelerated rate than could be injected solely through the central well 11. This result is of course obtained by the injection of water first through alternate wells and then through the remaining wells of the surrounding wells disposed about the central well, which wells penetrate the reservoir. However, in a random arrangement of wells, and also some uniform and regular geometric well patterns, it may be desirable by the term "alternate wells" to include wells which are not truly adjacent one another. For example, several wells, having a plurality of wells therebetween, disposed in a surrounding disposition about a central well may be used with the remainder of the surrounding wells being closed off during the step of water injection or the step of oil production. Also, the selection of wells for the injection of water and the production of oil to form the continuous water bank 20 in the reservoir 10 may be made with reference to the fluid flowing characteristics of the reservoir 10. For example, the water injection wells may be arranged, or selected, along distances proportional to the fluid flow anisotropy of the reservoir 10 so that a continuous, and preferably annular, water bank 20 may be formed.

The remaining steps of producing crude oil by miscible displacement procedures are as follows. Although a specific miscible fluid and driving fluid are described relative to a miscible displacement procedure, any miscible displacement fluid may be used. A liquid LPG slug 21 is injected into the reservoir 10 through the central well 11 behind the water bank 20. The volume of the LPG slug 21 may be readily determined by those skilled in the art and usually will be in the amounts used in conventional miscible displacement procedures. Miscible fluids other than LPG can be used if desired. Thereafter, the LPG slug 21 is driven radially outwardly through the reservoir 10 by injecting a noncondensing driving fluid 22, such as natural gas, through the central well 11. Other driving fluids may be used if desired. The LPG slug 21 driven by the injected driving fluid 22 moves the water bank 20 radially outwardly from the central well 11 while establishing miscibility pressure. Alternatively, a miscible displacement fluid, such as enriched natural gas, may be used. If desired, water may be continuously injected into one or more of the wells disposed surrounding about the central well 11 to maintain the water bank 20 in dynamic amounts or configurations during such miscible displacement procedure, or for other reasons. For example, water may be continuously injected into one or more of the wells 12 through 19, inclusively, during the step of driving the LPG slug 21 radially outwardly through the reservoir 10. The in situ crude oil displaced by the radial outward movement of the water bank 20 can be produced from the wells in the reservoir 10 surrounding the water bank 20. Of course, where water is continuously injected through one or more of the wells 12 through 19, inclusively, these wells are closed off when reached by the LPG slug 21.

If desired, the present invention is adapted to the use of a plurality of continuous water banks with each bank disposed in a different radial or vertical spaced relationship about the central well 11. This may be useful in reservoirs in which there are permeability variations along radial or vertical dimensions relative to the central well 11. This plurality of water banks will permit the reservoir characteristics to be altered during the radial

5

outward movement of the LPG slug 21, or with other miscible displacement fluids. Similarly, other modifications of the steps of the present invention may be utilized where a continuous water bank is formed in a reservoir in spaced relationship about a central well to obtain the stated results of this invention.

From the foregoing, it will be apparent that the disclosed novel method satisfies all the stated objects of this invention. The description of the method of this invention is to be taken as a means of illustration and not as a limitation of this invention. Various changes and modifications can be made to the present method by those skilled in the art without departing from the scope of the present invention. It is intended that such changes and modifications are to be included within the scope of the present invention, and that the only limitations to be applied are those found in the following appended claims.

What is claimed is:

1. A method for recovering oil from a subterranean reservoir penetrated by a plurality of wells comprising the steps of:

- (a) forming in the reservoir a continuous bank of water in spaced relationship about a central well by injecting water into the reservoir through a plurality of surrounding wells, and
- (b) producing oil from the reservoir through wells other than the wells being used for injecting the bank of water;
- (c) injecting a miscible displacement fluid through the central well into the reservoir behind the bank of water, and
- (d) driving the miscible displacement fluid radially outwardly through the reservoir from the central well and producing oil from the wells in the reservoir surrounding the bank of water.

2. The method of claim 1 wherein water is continuously injected through the plurality of surrounding wells to increase the size of the bank of water formed in the reservoir and closing off such wells as the miscible displacement fluid reaches them.

3. A method for recovering oil from a subterranean reservoir penetrated by a plurality of wells comprising the steps of:

- (a) injecting water through alternate wells into the reservoir and producing oil from the reservoir through the remaining wells in a plurality of wells surrounding a central well in spaced relationship therefrom until the water breaks through into the remaining wells,
- (b) injecting water into the reservoir through the remaining wells in such surrounding disposition until a continuous bank of water is formed about the central well in the reservoir and then closing off these remaining wells, and
- (c) producing oil from the reservoir through one or more wells other than the wells being used for the injection of water;
- (d) injecting a miscible displacement fluid through the central well into the reservoir behind the bank of water, and
- (e) driving the miscible displacement fluid radially outwardly through the reservoir by injecting a driving fluid through the central well and producing oil from the wells in the reservoir surrounding the bank of water.

4. A method for recovering oil from a subterranean reservoir penetrated by a plurality of wells comprising the steps of:

- (a) injecting water into the reservoir through alternate wells and producing oil from the reservoir through the remaining wells in a plurality of wells annularly disposed in spaced relationship about a central well,
- (b) closing off the alternate wells when the water breaks through into the remaining wells,

6

(c) injecting water into the reservoir through the remaining wells until a continuous bank of water is formed annularly in the reservoir about the central well and then closing off the remaining wells, and

- (d) producing oil from the reservoir through wells other than the wells used for the injection of water;
- (e) injecting a miscible displacement fluid through the central well into the reservoir behind the bank of water, and
- (f) driving the miscible displacement fluid radially outwardly through the reservoir by injecting a driving fluid through the central well and producing oil from the wells in the reservoir surrounding the bank of water.

5. The method of claim 4 wherein the injection of water through at least some of the annularly disposed wells is continued to increase the size of the bank of water formed in the reservoir and closing off such wells when the miscible displacement fluid reaches them.

6. A method for recovering oil from a subterranean reservoir penetrated by a plurality of wells comprising the steps of:

- (a) injecting water into the reservoir through some of the wells annularly disposed in spaced relationship about a central well and producing oil from the reservoir through some of the remaining wells in such annular disposition,
- (b) closing off the wells used for water injection when the water breaks through into the wells in such annular disposition used for producing oil,
- (c) injecting water into some of the remaining wells annularly disposed in spaced relationship about the central well until a continuous bank of water is formed annularly in the reservoir about the central well and then closing off the wells used for water injection, and
- (d) producing oil from the reservoir through wells other than the wells used for injection of water;
- (e) injecting a miscible displacement fluid through the central well into the reservoir behind the bank of water, and
- (f) driving the miscible displacement fluid radially outwardly through the reservoir and producing oil from the wells in the reservoir surrounding the bank of water.

7. The method of claim 6 wherein the injection of water through at least some of the annularly disposed wells is continued to increase the size of the bank of water formed in the reservoir and closing off such wells when the miscible displacement fluid reaches them.

8. A method for recovering oil from a subterranean reservoir penetrated by a plurality of wells disposed in a regular and uniform geometric pattern comprising the steps of:

- (a) forming in the reservoir a continuous bank of water in spaced relationship about a central well by injecting water into the reservoir through the wells in the rows and lines of wells adjacent to the central well, and
- (b) producing oil from the reservoir through wells other than the wells being used for injecting the bank of water;
- (c) injecting a miscible displacement fluid through the central well into the reservoir behind the bank of water, and
- (d) driving the miscible displacement fluid radially outwardly through the reservoir from the central well and producing oil from the wells in the reservoir surrounding the bank of water.

9. The method of claim 8 wherein the water is continuously injected through the wells in the rows and lines of wells adjacent to the central well to increase the size of the bank of water formed in the reservoir and closing off such wells when the miscible displacement fluid reaches them.

10. A method for recovering oil from a subterranean reservoir penetrated by a plurality of wells disposed in a regular and uniform geometric pattern comprising the steps of:

- (a) forming a continuous bank of water in the reservoir about a central well by injecting water into the reservoir through alternate wells in the rows and lines of wells adjacent to the central well and producing oil from the reservoir through the remaining wells in such rows and lines of wells, 5
- (b) closing off the wells used for injecting water when the water breaks through into the wells in such rows and lines of wells producing oil, 10
- (c) injecting water into the reservoir through the wells in such rows and lines of wells formerly used for producing oil until a continuous bank of water is formed annularly in the reservoir about the central well and then closing off the wells, and 15
- (d) producing oil from the reservoir through wells other than the wells used for the injection of water; 20
- (e) injecting a miscible displacement fluid through the central well into the reservoir behind the tank of water, and
- (f) driving the miscible displacement fluid radially outwardly through the reservoir from the central well and producing oil from the wells in the reservoir surrounding the bank of water. 25

11. The method of claim 10 wherein the water is continuously injected through the wells in the rows and lines of wells adjacent to the central well to increase the size of the bank of water formed in the reservoir and closing off such wells when the miscible displacement fluid reaches them. 30

12. A method for recovering oil from a subterranean reservoir penetrated by a plurality of wells disposed in a regular and uniform geometric pattern comprising the steps of: 35

- (a) forming a continuous bank of water in the res-

ervoir about a central well by injecting water into the reservoir through some of the wells in the rows and lines of wells adjacent to the central well and producing oil from the reservoir through the remaining wells in such rows and lines of wells,

- (b) closing off the wells used for injecting water when the water breaks through into the wells in such rows and lines of wells producing oil,
- (c) injecting water into the reservoir through the wells in such rows and lines of wells formerly used for producing oil until a continuous bank of water is formed annularly in the reservoir about the central well and then closing off the wells, and
- (d) producing oil from the reservoir through wells other than those used for the injection of water;
- (e) injecting a miscible displacement fluid into the reservoir through the central well behind the bank of water, and
- (f) driving the miscible displacement fluid radially outwardly through the reservoir from the central well and producing oil from the wells in the reservoir surrounding the bank of water.

13. The method of claim 12 wherein the water is continuously injected through the wells in the rows and lines of wells adjacent to the central well to increase the size of the bank of water formed in the reservoir and closing off such wells when the miscible displacement fluid reaches them.

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