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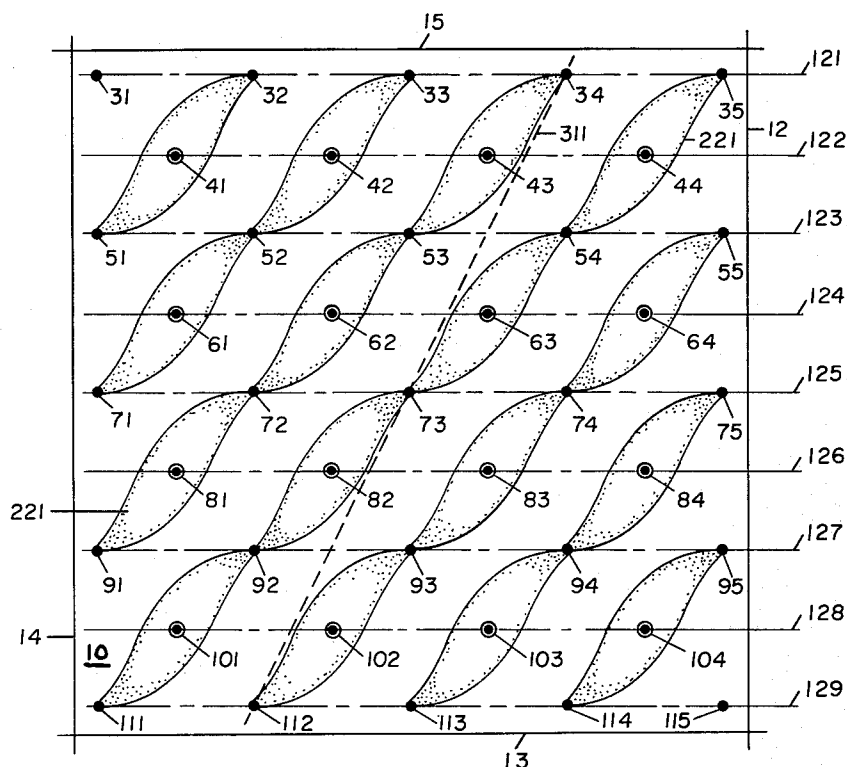
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3,256,934

PETROLEUM SECONDARY RECOVERY METHOD FOR OIL-BEARING RESERVOIRS
EXHIBITING UNIFORM ANISOTROPIC PERMEABILITY

Filed March 21, 1963

2 Sheets-Sheet 1



LEGEND

- - PRODUCTION WELL
- ⊙ - INJECTION WELL
- DIRECTION OF GREATEST PERMEABILITY

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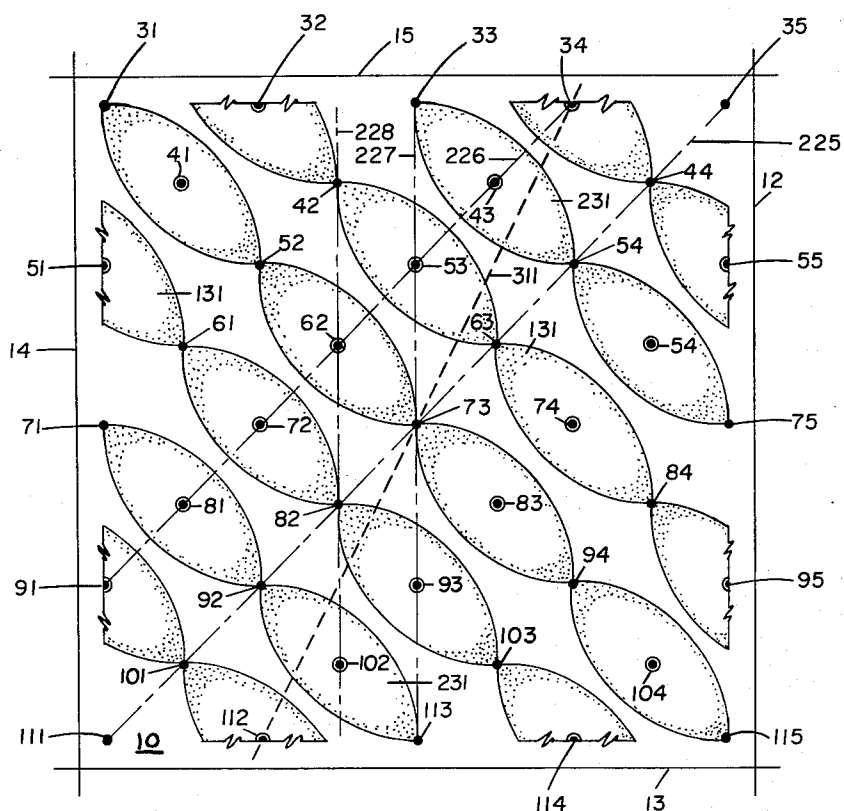


FIG. 2.

LEGEND

- - PRODUCTION WELL
- ⊙ - INJECTION WELL
- DIRECTION OF GREATEST PERMEABILITY

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**PETROLEUM SECONDARY RECOVERY METHOD
FOR OIL-BEARING RESERVOIRS EXHIBITING
UNIFORM ANISOTROPIC PERMEABILITY****George W. Nabor, Dallas, Tex., and Mohamed Mortada,
Jamaica, N.Y., assignors to Socony Mobil Oil Com-
pany, Inc., a corporation of New York****Filed Mar. 21, 1963, Ser. No. 266,947****8 Claims. (Cl. 166-9)**

This invention relates to the recovery of petroleum and, more particularly, it relates to secondary recovery methods.

Petroleum is recovered from subterranean reservoirs by means of petroleum producing wells. Generally, a plurality of wells are required to obtain satisfactory recovery of the petroleum available in a reservoir in a reasonable length of time. The wells are usually spaced from one another at a uniform distance. One reason for this is that an irregular spacing of wells requires more wells for a given reservoir than a regular spacing of wells to produce the same quantity of petroleum under the same conditions. The actual well spacing distance is primarily determined by the area of the reservoir drained by each well. As a result, the wells are uniformly disposed at such spacing from one another over the surface area available for drilling into the reservoir. As an example of actual well spacing, the wells may be spaced from one well on about each 3 acres to one well on each 40 acres or more. Thus, the wells are disposed at the desired spacing to form a geometric pattern which best covers the surface area available for drilling in the most economic manner.

In any geometric pattern, the wells will be located in the reservoir in straight, parallel rows. The wells are disposed in each of the rows at a uniform distance from one another. Further, the rows of wells are spaced from one another by a uniform distance. The particular distance between wells or rows of wells is controlled by the type of geometric well pattern. Usually, only a secondary consideration of the physical and chemical conditions present in the reservoir is given in determining the well spacing. This is a satisfactory practice in isotropic reservoirs which have the same permeability in all directions. As a result, the rows of wells are arranged parallel to geographical boundaries. In some geometric patterns the rows of wells extend north and south, or east and west.

Generally, the geometric pattern of wells is usually fully developed by the time the primary recovery method fails economically to produce the reservoir, and secondary recovery methods become necessary. The geometric pattern of wells used for primary recovery is used, at least in part, for secondary recovery by selecting some wells for injection and other wells for production.

The geometric patterns generally are satisfactory for secondary recovery methods where the reservoir has isotropic permeability, i.e., the same permeability exists in all directions. However, when secondary recovery methods are applied with conventionally placed geometric patterns in a reservoir exhibiting pronounced anisotropic permeability, the petroleum recovery from the secondary recovery methods can be severely reduced. This result is produced by the flow of fluids being unequal in all directions in reservoirs exhibiting significant anisotropic permeability. Therefore, in secondary recovery methods, the injected driving fluid prematurely breaks through into the adjacent production wells so that only a small portion of the reservoir is swept by the petroleum-displacing fluid during maximum rate of petroleum production. For example, only 45-55 percent of the reservoir may be swept before breakthrough of the driving fluid at the

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production wells occurs. The remaining petroleum may be recovered at a decreasing rate of petroleum production over an extended period of time.

It is therefore an object of the present invention to provide an efficient method of petroleum recovery from reservoirs exhibiting anisotropic permeability.

Another object of the present invention is to provide a method for recovering petroleum from reservoirs exhibiting anisotropic permeability using conventional secondary recovery methods by locating injection and production wells in an existing geometric pattern of wells.

Another object of the present invention is to provide a method for recovering petroleum at greater petroleum production rates and increased total petroleum recoveries from existing petroleum recovering wells in a reservoir exhibiting anisotropic permeability than heretofore possible.

Another object of this invention is to provide a method for recovery of petroleum from a reservoir having anisotropic permeability by secondary methods where the different directional permeabilities do not substantially reduce the rates or amounts of petroleum available for recovery.

Another object is to provide a method in accordance with the preceding object wherein the anisotropy of the reservoir is utilized to advantage rather than being a detriment to petroleum recovery.

Another object of this invention is to provide a method of determining the use as injection or production wells of all the wells in existing geometric patterns to optimize the recovery of petroleum from an anisotropic permeable reservoir by any conventional secondary recovery method.

These and other objects will become more apparent when read in conjunction with the following detailed description of one illustrative embodiment of the present invention, the attached drawings, and the appended claims.

Referring now to the drawings, in FIGURE 1 there is shown the flood patterns of a driving fluid in a conventional secondary recovery method using a "5-spot" geometric pattern in the manner of the prior art in a reservoir exhibiting anisotropic permeability; and in FIGURE 2 there is shown the same reservoir and geometric well pattern with the driving fluid flood patterns, of the secondary recovery method, in accordance with the present invention.

The objects of the present invention are obtained by a method comprising the steps of producing petroleum by injecting a driving fluid through certain wells and producing petroleum through other wells wherein the wells of an existing geometric pattern are arranged in a particular and unconventional manner of alternate rows of injection and production wells.

Referring now to FIGURE 1 of the drawings, a conventional secondary recovery method for recovering petroleum from a reservoir exhibiting anisotropic permeability using the conventional arrangement of wells of a regular, uniform, geometric well pattern into alternate rows of injection and production wells will be described. In FIGURE 1 there is shown in diagrammatic illustration a portion of a reservoir 10 penetrated by a plurality of equally spaced wells arranged in equally spaced rows to form a geometric pattern. As an example, wells 31 to 35, 41 to 44, 51 to 55, 61 to 64, 71 to 75, 81 to 84, 91 to 95, 101 to 104, and 111 to 115 have been placed at equal or uniform spacing in several rows 121 to 129, respectively, to form a geometric well pattern covering the reservoir 10. The geometric pattern may have been provided for primary petroleum recovery. The wells in the several rows 121 to 129 are so arranged that alternate rows 121, 123, 125, 127, and 129 are shifted parallel to rows 122, 124, 126, and 128 by half the spacing between the wells in the

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rows. The rows 121 to 129 are separated by half the spacing or distance of the spacing between wells in a row. This is commonly denoted as a staggered pattern. To those skilled in the art it is known as a "5-spot" pattern. The several rows of wells parallel the geographical boundaries 12, 13, 14, and 15 of the reservoir 10 and thus run north and south or east and west. Other types of geometric well patterns may be used as will be obvious to one skilled in the art from this description.

It has been the practice to use conventional secondary recovery methods when primary recovery methods in the reservoir fail to produce sufficient petroleum recovery. For example, one secondary recovery method for the conventional "5-spot" pattern uses the wells in the alternate rows 122, 124, 126, and 128 as injection wells and the wells in the remaining rows 121, 123, 125, 127, and 129 as production wells. The pattern of wells shown in FIGURE 1 will produce an efficient recovery of petroleum remaining in the reservoir by conventional secondary recovery methods when the reservoir has isotropic permeability. One reason is that the flood patterns of the driving fluid advance uniformly and flood substantially all of the reservoir before the driving fluid breaks through at the production wells. However, when the reservoir has anisotropic permeability, a secondary recovery method applied to the existing geometric pattern in accordance with the prior art does not produce efficient recovery of the available petroleum. One reason for this is that the driving fluid tends to cover only a small portion of the reservoir 10 about the injection wells before severe and premature breakthrough of the driving fluid occurs at the production wells. For the purpose of illustrating this invention, the result of applying a secondary recovery method to an anisotropically permeable reservoir 10 is shown in FIGURE 1. The anisotropic permeability of the reservoir 10 will be considered as having a ratio of the greatest permeability to the least permeability of 3 to 1. Further, the direction of greatest permeability is indicated by the chain-line 311 which extends off vertically through the reservoir 10 at an angle of about 20 degrees. Also, the reservoir may be considered to be of uniform thickness and porosity. The permeability may be considered to be uniformly anisotropic with each principal axis of permeability maintaining the same direction and magnitude at every point in the reservoir 10. Two of the principal axes of permeability lie in the bedding plane at right angles to one another, and the third axis of permeability is perpendicular to them. Usually, the forces of gravity may be neglected. Thus, the anisotropic permeability axes comprise solely the direction of greatest permeability and the direction of least permeability which directions reside in the bedding plane.

Many conventional secondary recovery methods are known and in these a driving fluid is injected at one or more well locations for flooding a reservoir. Various types of driving fluids are employed. Water and lean gas are examples of immiscible driving fluids. High pressure gas, enriched gas, or liquefied petroleum gas (LPG) slugs are examples of miscible driving fluids. Other fluids can be used as driving fluids if desired. The driving fluid in the present examples is water.

More specifically, with further reference to FIGURE 1, the production wells and injection wells are located in the conventional "5-spot" patterning for secondary recovery of petroleum. The driving fluid is injected at substantially equal rates through the wells 41 to 44, 61 to 64, 81 to 84, and 101 to 104. The driving fluid displaces the petroleum in the reservoir 10 to the production wells 31 to 35, 51 to 55, 71 to 75, 91 to 95, and 111 to 115. The petroleum may be recovered from the production wells by suitable means. For example, the petroleum may be pumped from the wells to the surface of the earth as one means of recovery. As can be seen in FIGURE 1, the wells in the rows of wells 122,

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124, 126, and 128 are utilized for injecting a suitable driving fluid into the reservoir. The wells in the rows of wells 121, 123, 125, 127, and 129 are utilized for recovering petroleum from the reservoir 10. Flood patterns 221 formed by the injected driving fluid are illustrated by the shaded areas in FIGURE 1 at the time of initial breakthrough of the driving fluid to the production wells in rows 121, 123, 125, 127, and 129.

As a result of the anisotropic permeability of the reservoir 10, the flood patterns 221 do not advance uniformly and flood substantially all of the reservoir before breakthrough as they would in an isotropic permeable reservoir. Rather, the flood patterns 221 produced by the injected driving fluid are very greatly noncircular. Thus, the driving fluid breakthrough occurs early in the development of the flood patterns 221 at the production wells in rows 121, 123, 125, 127, and 129. Therefore, the area of the reservoir swept by the conventional secondary recovery method before the breakthrough is small. For example, in FIGURE 1 the flood patterns 221 have covered only about 45-55 percent of the reservoir 10 before breakthrough. Stated in another manner, the unshaded area between the flood patterns 221 is large relative to the shaded area of the flood patterns 221 at breakthrough. The shaded area represents the amount of the reservoir that is swept by the driving fluid. This premature breakthrough of the driving fluid at the production well produces several undesired results which severely limit the rate of petroleum recovery and also the total amount of petroleum recovered during the secondary method. One result is that only a small portion of the petroleum in the reservoir is recovered at the full productive capacity of the secondary recovery method before the driving fluid breaks through at the production wells in rows 121, 123, 125, 127, and 129. Further, to recover the remaining petroleum, additional quantities of driving fluid must be injected through the injection wells in rows 122, 124, 126, and 128 and circulated through the reservoir for expanding the flood patterns 221 along the direction of least permeability. At such time, the production wells in rows 121, 123, 125, 127, and 129 will produce a mixture of petroleum and the driving fluid. The ratio of petroleum to driving fluid recovered through the production wells increases steadily during expansion of the flooding patterns 221 through the reservoir 10. Consequently, the time required to recover a given quantity of petroleum is greatly increased. As a matter of conservation, the excess quantities of driving fluid produced at the production well must be recycled to the injection wells. The cost of recovering a given quantity of petroleum is thereby greatly increased.

Referring now to FIGURE 2 of the drawings, an illustrative embodiment of the present invention will be described as practiced on the reservoir 10 by means of the wells in the geometric well pattern shown in FIGURE 1. As a step of the method, the direction and magnitude of greatest permeability and the magnitude of least permeability are determined. This step is not necessary, of course, where the desired information is available from prior investigations performed at the location of the wells in the geometric pattern for primary petroleum production or from other sources.

The permeability magnitudes and their directions may be determined by any suitable means. For example, cores taken from various portions of the reservoir can be analyzed to determine the directions and magnitudes of the greatest and least permeabilities. An analysis which provides the direction of greatest permeability and the ratio of the magnitudes of greatest and least permeability can also be used as will be hereafter apparent. Another means to obtain this information is by fluid injection in one well and measuring the pressure or fluid flow increase in the surrounding wells. Other means to obtain this information will be apparent to those skilled in the art.

As another step in this invention, a row of wells is located from the geometric pattern of wells in FIGURE 2 in the greatest possible alignment with the direction of greatest permeability, as designated by chain-line 311. For the purposes of this invention, by a row of wells is meant wells disposed substantially along a straight line but not necessarily on such line. The acute angle formed by the direction of greatest permeability and such row of wells is determined by conventional methods. The next adjacent row of wells in alignment with the first-mentioned row of wells is located. Successive rows of wells are located, each row being in next greatest alignment with the direction of greatest permeability. Also located is the next adjacent row of wells in alignment with each such successive row in next greatest alignment with the direction of greatest permeability. The acute angle formed between the direction of greatest permeability and each such rows of wells is determined by conventional methods. For example, referring to FIGURE 2, the first row of wells 225 located may comprise wells 35, 44, 54, 63, 73, 82, 92, 101, and 111. The second row of wells 226 located next adjacent to and in alignment with this row of wells may comprise wells 34, 43, 53, 62, 72, 81, and 91. The next successive row of wells 227 located in next greatest alignment with the direction of greatest permeability may comprise wells 33, 53, 73, 93, and 113. The next adjacent row of wells 228 in alignment with row of wells 227 may comprise wells 42, 62, 82, and 102. The acute angle formed between these rows of wells and direction of permeability is determined. It is obvious that several other possible rows of wells can be located in FIGURE 2 from the "5-spot" pattern presently in existence in the same manner. Likewise, the acute angle formed between these rows and chain-line 311 is determined.

Another step in this invention is to determine the spacing between wells in each of the rows 225, 226, 227, 228, and in any of the other rows located in the "5-spot" pattern of FIGURE 2. Also, the spacing taken perpendicularly between adjacent parallel rows of wells is determined. Thus, the spacing or distance between rows 225 and 226, between rows 227 and 228, and between any of the other rows is determined. The spacing may be measured or determined by other suitable means.

The rows of wells which traverse the reservoir are in equally spaced, parallel relationship and the wells in each row are at equal spacings from one another when the geometric pattern is regular and uniform. The present invention is also applicable to situations where the spacing may vary between adjacent wells in each row, or between the adjacent parallel rows of wells, or both. However, where such variations do occur, the spacings should be determined by averaging the several spacings between wells in each row or between next adjacent rows. However, the petroleum recovery will be somewhat less than the recovery obtained in an exactly uniform well and row spacing in regular, uniform, geometric well patterns. Wells may be drilled in the desired geometric pattern where such do not exist prior to the need for a secondary recovery method in the reservoir. Any existing wells not in the desired geometric well pattern may be "shut-in."

In accordance with this invention, a driving fluid is injected at equal rates through wells in one row of the wells and petroleum produced from a second row of wells next adjacent to and in alignment with said one row of wells where these rows of wells provide a maximum constant C from the following formula:

$$C = \frac{d}{a} \left[\frac{\sqrt{kd/ka}}{[(kd/ka) - 1] \sin^2 \theta + 1} \right]$$

In the formula, d is the perpendicular spacing between rows of wells and a is the well spacing within the rows. In the formula, kd is the permeability in the direction of greatest permeability and ka is the permeability in the direction of least permeability. In the formula, θ is the

acute angle formed between the rows of wells and the direction of greatest permeability.

More particularly, the following method of secondary recovery of petroleum is practiced assuming the rows of wells 225 and 226 provide a maximum constant C relative to the rows 227 and 228, or any other rows located in the geometric pattern of FIGURE 2. The wells 34 through 91 in row 226 are used as injection wells for injecting a suitable driving fluid into the reservoir. The injection wells may be provided with suitable means for conveying the driving fluid into the reservoir. The wells 44 through 101 in row 225 are used as production wells for recovering petroleum from the reservoir. The production wells may be provided with suitable means for recovering petroleum from the reservoir. The wells in each alternate row of wells parallel to row 226 may be used as injection wells. The wells in each alternate row of wells parallel to row 225 may be used as production wells. Thus, the rows of injection and production wells can be extended to cover the entire reservoir. Injecting the driving fluid at equal rates through the injection wells 34 through 91 in row 226 and the injection wells in each alternate row therefrom produces flood patterns 231. Flood patterns 231 are indicated by the shaded areas in FIGURE 2. The flood patterns 231 are shown at the initial breakthrough of the driving fluid at the production wells 44 through 101 in row 225 and at production wells in each alternate row therefrom. The flood patterns 231 and 221 are drawn to substantially the same scale in both FIGURES 1 and 2 and provide a visual comparison of the flood patterns obtained by the methods of the prior art and the methods of the present invention, respectively. The area of the flood patterns 231 produced by practicing the present invention is about twice the area of the flood patterns 221 obtained by the prior art methods at the initial breakthrough of driving fluid at the production wells.

Referring again to FIGURE 2, it is seen that each row 225 or 226 has wells of the same type. They are either injection wells in row 226 or production wells in row 225. This is the preferable arrangement. It may be found desirable to use one or more wells in a given row of a type other than used in such row. As an example, to provide offset wells, or for other reasons, an injection well or production well may be placed adjacent the extremities of the reservoir, such as at wells 35 or 111.

The utility and operability of this invention is readily determinable by calculation of the areal sweep efficiency and flow capacity for resulting flood patterns 231 obtained by the secondary recovery method of this invention. For comparison, a similar determination may be made of flood patterns 221 of the prior art methods. Reference may be had to the publication entitled, "An Approximate Method for Determining Areal Sweep Efficiency and Flow Capacity in Formations with Anisotropic Permeability," in the December 1961, issue of Society of Petroleum Engineers Journal at pages 277-286 for suitable equations to perform these calculations. A potentiometric analog analysis produces substantially the same determination and information as is apparent to one skilled in the art.

By reference to FIGURES 1 and 2, it will be seen that a given rate of petroleum recovery by the secondary recovery method in accordance with the present invention is maintained until approximately 85 to 95 percent of the reservoir has been flooded. By comparison, the prior art secondary recovery method illustrated in FIGURE 1, in the same reservoir, the same given rate of petroleum reservoir is maintained until only a maximum of about 45 to 55 percent of the reservoir has been flooded. It will be obvious that the present invention provides about a 200 percent increase in petroleum recovery from the same reservoir before the driving fluid flood patterns 231 reach the nearest production wells.

It will be noted also from FIGURE 2 that the rows of wells located in accordance with the present inven-

tion for use in injection and for producing petroleum involve the use of substantially all of the wells in the original geometric pattern covering the reservoir. This is a great advantage because the amount of available petroleum in the reservoir can be recovered at much greater total rates with the same injection rates of driving fluid using all of the wells than when only some of the wells are used with the remaining wells "shut-in."

Further, in determining which of the rows of wells most closely in alignment with the direction of greatest permeability are to be used in the secondary recovery methods, no rows of wells are skipped. Stated in another manner, the present invention requires that each adjacent row of wells be used as injection or production wells for the secondary recovery of petroleum from the reservoir. As a result, the well density in the reservoir used for recovery of petroleum is at a maximum. This prevents the excessive drainage losses of petroleum from the reservoir to wells on adjacent leases. By the present invention, a greater quantity of petroleum can be recovered from the reservoir before breakthrough of the driving fluid at the production wells. Thus, the cost of the secondary recovery method is greatly reduced. Also, the petroleum is recovered from the production wells at a greater rate than in conventional secondary recovery methods. As a result, the petroleum can be recovered more completely in a shorter period of time. Further, after breakthrough of the driving fluid at the production wells, further quantities of petroleum can be recovered with less cost in recirculating the driving fluid recovered from the production wells to the injection wells than in the conventional secondary recovery methods illustrated in FIGURE 1.

It will be seen from the foregoing description that the method of the present invention can be used with any secondary recovery method in reservoirs provided with wells arranged in any geometric pattern. No experimentation as to pilot secondary recovery projects is necessary. Various modifications of the present invention may be made by those skilled in the art, and it is intended that such modifications be within the scope of the appended claims. The foregoing description is intended to be for the purposes of illustrating the present invention and is not to be interpreted as limiting.

What is claimed is:

1. A secondary recovery method for producing petroleum from an oil-bearing reservoir exhibiting uniform anisotropic permeability where a plurality of wells disposed in spaced rows in a geometric pattern penetrate such reservoir and such wells spaced in each such row for the production of petroleum, the steps comprising injecting a driving fluid through one row of wells and producing petroleum from a second row of wells adjacent to and in alignment with said one row of wells, said rows of wells being oriented with respect to said reservoir so as to provide a maximum constant C using the formula

$$C = \frac{d}{a} \left[\frac{\sqrt{kd/ka}}{[(kd/ka) - 1] \sin^2 \theta + 1} \right]$$

where in the formula d is the perpendicular spacing between rows of wells, a is the well spacing within the rows, kd is the permeability in the direction of greatest permeability, ka is the permeability in the direction of least permeability, and θ is the acute angle formed between the rows of wells and the direction of greatest permeability.

2. The method of claim 1 wherein the driving fluid is water.

3. A secondary recovery method for producing petroleum from an oil-bearing reservoir exhibiting uniform anisotropic permeability where a plurality of wells disposed in spaced rows in a geometric pattern penetrate

such reservoir and such wells spaced in each such row for the production of petroleum, the steps comprising:

- (a) determining the direction and magnitude of greatest permeability and the magnitude of the permeability in the direction of least permeability,
- (b) locating the row of wells in the greatest alignment with the direction of greatest permeability,
- (c) determining the acute angle formed between the direction of greatest permeability and such row of wells,
- (d) locating another row of wells next adjacent to and in alignment with the first-mentioned row of wells,
- (e) determining the perpendicular distance between the rows of wells and the average distance between wells in the rows of wells,
- (f) repeating the above steps (c) and (e) for each successive row of wells in next greatest alignment with the direction of greatest permeability after said first-mentioned row of wells and the row of wells adjacent to and in alignment with each such successive row, and
- (g) injecting a driving fluid through wells in at least one said row of wells and producing petroleum from wells in at least another row of wells adjacent to and in alignment with said one row of wells containing wells for injecting driving fluid, said rows of wells being oriented with respect to said direction of greatest permeability so as to provide a maximum constant C from the located rows of wells using the formula

$$C = \frac{d}{a} \left[\frac{\sqrt{kd/ka}}{[(kd/ka) - 1] \sin^2 \theta + 1} \right]$$

where in the formula d is the perpendicular spacing between rows of wells, a is the well spacing within the rows, kd is the permeability in the direction of greatest permeability, ka is the permeability in the direction of least permeability, and θ is the acute angle formed between the rows of wells and the direction of greatest permeability.

4. A secondary recovery method for producing petroleum from an oil-bearing reservoir exhibiting uniform anisotropic permeability where a plurality of wells disposed in spaced rows in a geometric pattern penetrate such reservoir and such wells spaced in each such row for the production of petroleum, the steps comprising:

- (a) determining the direction and magnitude of greatest permeability and the magnitude of the permeability in the direction of least permeability,
- (b) locating several adjacent parallel rows of wells traversing the reservoir,
- (c) determining the acute angle formed between the direction of greatest permeability and each such adjacent rows of wells,
- (d) determining the average perpendicular distance between the adjacent parallel rows of wells and the average distance between wells in the rows, and
- (e) injecting a driving fluid through wells in at least one said row of wells and producing petroleum from wells in at least another row of wells adjacent to and in alignment with said one row of wells containing wells for injecting driving fluid, said rows of wells being oriented with respect to said direction of greatest permeability so as to provide a maximum constant C from the located parallel rows of wells using the formula

$$C = \frac{d}{a} \left[\frac{\sqrt{kd/ka}}{[(kd/ka) - 1] \sin^2 \theta + 1} \right]$$

where in the formula d is the perpendicular spacing between rows of wells, a is the well spacing within the rows, kd is the permeability in the direction of greatest permeability, ka is the permeability in the direction of least permeability, and θ is the acute

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angle formed between the rows of wells and the direction of greatest permeability.

5. The method of claim 4 wherein the driving fluid is water.

6. A secondary recovery method for producing petroleum from an oil-bearing reservoir exhibiting uniform anisotropic permeability where a plurality of wells disposed in spaced rows in a geometric pattern penetrate such reservoir and such wells spaced in each such row for the production of petroleum, the steps comprising injecting a driving fluid through wells in each alternate row of wells extending substantially across the reservoir in the same direction and producing petroleum from wells in the remaining rows of wells extending substantially across the reservoir, said remaining rows of wells being adjacent to and in alignment with said alternate rows of wells, said rows of wells being oriented with respect to said reservoir so as to provide a maximum constant C using the formula

$$C = \frac{d}{a} \left[\frac{\sqrt{kd/ka}}{[(kd/ka) - 1] \sin^2 \theta + 1} \right]$$

where in the formula d is the perpendicular spacing between rows of wells, a is the well spacing within the rows, kd is the permeability in the direction of greatest permeability, ka is the permeability in the direction of least permeability, and θ is the acute angle formed between the rows of wells and the direction of greatest permeability.

7. A secondary recovery method for producing petroleum from an oil-bearing reservoir exhibiting uniform anisotropic permeability where a plurality of wells disposed in spaced rows in a geometric pattern penetrate such reservoir and such wells spaced in each such row for the production of petroleum, the steps comprising injecting a driving fluid through wells in each alternate row of wells and producing petroleum from wells in each of the remaining rows of wells adjacent to at least one of said alternate rows of wells into which is injected the driving fluid, said alternate and remaining rows of wells being parallel to one another and traversing the reservoir, said rows of wells being oriented with respect to said

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reservoir so as to provide a maximum constant C using the formula

$$C = \frac{d}{a} \left[\frac{\sqrt{kd/ka}}{[(kd/ka) - 1] \sin^2 \theta + 1} \right]$$

where in the formula d is the perpendicular spacing between rows of wells, a is the well spacing within the rows, kd is the permeability in the direction of greatest permeability, ka is the permeability in the direction of least permeability, and θ is the acute angle formed between the rows of wells and the direction of greatest permeability.

8. A secondary recovery method for producing petroleum from an oil-bearing reservoir exhibiting uniform anisotropic permeability where a plurality of wells disposed in spaced rows in a geometric pattern penetrate such reservoir and such wells spaced in each such row for the production of petroleum, the steps comprising injecting a driving fluid through equally spaced injection wells in each alternate row of wells and recovering petroleum from production wells in the remaining rows of wells wherein said production wells are spaced apart by substantially the same distance as the injection wells, said alternating and remaining rows of wells traversing the reservoir in parallel relationship at equal spacings from one another, said rows of wells being oriented with respect to said reservoir so as to provide a maximum constant C using the formula

$$C = \frac{d}{a} \left[\frac{\sqrt{kd/ka}}{[(kd/ka) - 1] \sin^2 \theta + 1} \right]$$

where in the formula d is the perpendicular spacing between rows of wells, a is the well spacing within the rows, kd is the permeability in the direction of greatest permeability, ka is the permeability in the direction of least permeability, and θ is the acute angle formed between the rows of wells and the direction of greatest permeability.

No references cited.

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