Sept. 14, 1965 S. M. FOULKS 3,205,943

RECOVERY METHOD FOR PETROLEUM

Filed Aug. 20, 1959

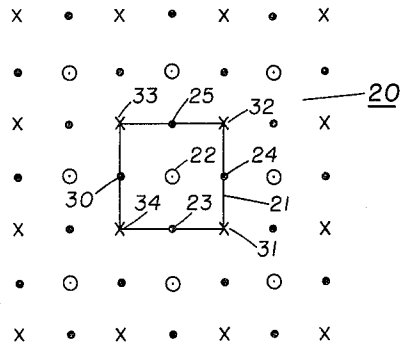


FIG. 1

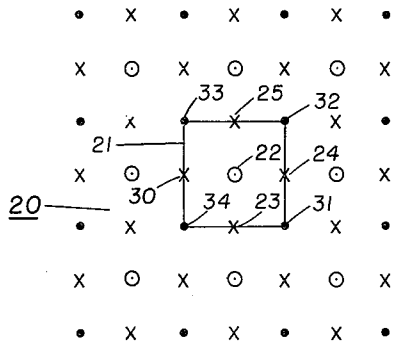


FIG. 2

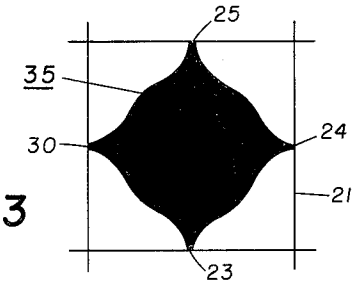


FIG. 3

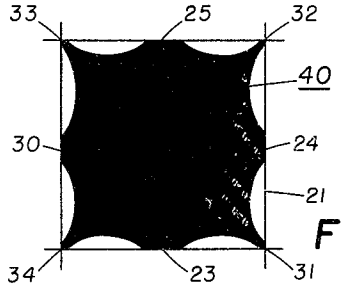


FIG. 4

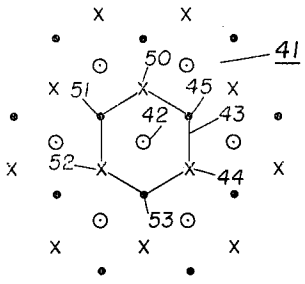


FIG. 5

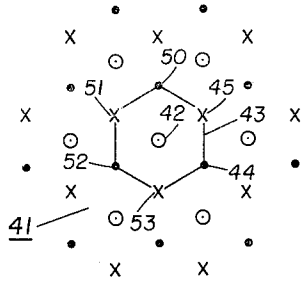


FIG. 6

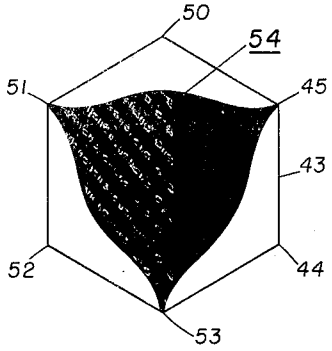


FIG. 7

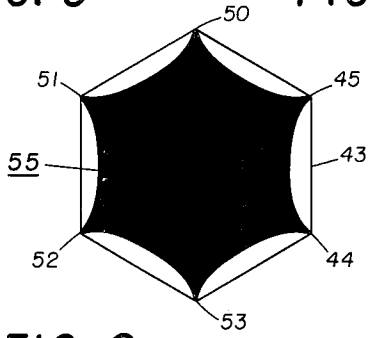


FIG. 8

SIDNEY M. FOULKS
INVENTOR.

BY Frederick E. Dumoulin
ATTORNEY

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RECOVERY METHOD FOR PETROLEUM

Sidney M. Foulks, Irving, Tex., assignor to Socony Mobil Oil Company, Inc., a corporation of New York

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This invention relates to the secondary recovery of petroleum from a subterranean formation and relates more particularly to the secondary recovery of petroleum from a subterranean formation by methods involving displacement of the petroleum within the formation by means of an injected fluid.

Petroleum is usually recovered initially from most subterranean formations as a result of gas pressure or natural water drive forcing the oil from the petroleum-bearing formation, or reservoir, to a producing well and to the surface of the earth. As recovery of petroleum from the formation continues, the reservoir energy gradually decreases and finally becomes insufficient to force the petroleum to the surface of the earth, although a major portion of the petroleum still remains in the reservoir. To recover petroleum from the reservoir, pumping may be employed but when the rate of recovery by pumping falls to an uneconomically low level, further petroleum may often be economically recovered by the employment of other secondary recovery methods. Various of these secondary recovery methods involve displacement of the petroleum within the formation to a producing well by injection into the formation through an injection, or input, well of a displacing fluid. This fluid may be a gas or a liquid. Included among these secondary recovery methods employing a displacing fluid are gas drive, water drive, miscible flooding and in-situ combustion.

In secondary recovery methods employing a displacing fluid, the displacing fluid travels from an injection well to a producing well in pathways, other things being equal, determined by the number and relative position of the injection and production wells. The petroleum within the pathways of travel of the displacing fluid in the formation will be the petroleum recovered by the recovery method while the remainder of the petroleum, lying outside the pathways of travel of the displacing fluid, will not be recoverable. The shape of the area of the formation within the pathways of travel of the displacing fluid is termed the "sweep pattern" and the ratio of the area within the sweep pattern to the area outside the sweep pattern is termed the "sweep efficiency." Practical operations from the standpoint of economy require the maximum sweep efficiency commensurate with the number of injection and production wells. Conventionally, the injection and production wells are arranged in rectangular patterns with an injection well surrounded by a plurality of production wells. While high areal sweep efficiencies are obtained with these well patterns, still higher efficiencies are desirable.

It is an object of this invention to improve the extent of recovery of petroleum from a subterranean formation. It is another object of this invention to obtain a greater sweep efficiency in a secondary recovery operation employing a displacing fluid. Further objects of the invention will become apparent from the following detailed description.

In accordance with the invention, in a secondary recovery operation for petroleum oil wherein a displacing fluid is injected into a subterranean formation through a central well and petroleum oil is displaced in the direction of and produced from a plurality of wells surrounding the central well, there are provided two steps. In the first step, displacing fluid is injected into the central well and petroleum oil is produced from every other one of the surrounding wells until breakthrough occurs at these surrounding wells. In the second step, each of these surrounding wells from which petroleum oil has been produced in the first step are shut off and with displacing fluid continued to be injected into the central well, petroleum oil is produced from each of the remaining surrounding wells.

FIGURES 1 and 2 are schematic diagrams illustrating an embodiment of the invention.

FIGURES 3 and 4 are schematic diagrams illustrating the sweep patterns obtained with the embodiment of the invention illustrated in FIGURES 1 and 2.

FIGURES 5 and 6 are schematic diagrams illustrating another embodiment of the invention.

FIGURES 7 and 8 are schematic diagrams illustrating the sweep patterns obtained with the embodiment of the invention illustrated in FIGURES 5 and 6.

Referring now to FIGURE 1, field 20 overlying a petroleum reservoir is provided with a plurality of wells. These wells are arranged in a regular, geometric, uniform pattern. Further, each well is located at the corner of a square. The pattern of the wells may also be described as being such that any one well, a central well, is surrounded by eight wells equidistantly spaced from each other.

For purposes of simplicity of description, reference will be made in FIGURE 1, as well as FIGURES 2, 5, and 6, to the wells within a circumscribed area. In FIGURE 1, this area is indicated by the numeral 21. However, it will be understood that operations with respect to the other wells in the field will be similar to those described with respect to the wells in the circumscribed area. In the figures, a ring containing a central dot signifies an injection well, a solid circle represents a production well, and a cross represents a well which has been shut in.

In the circumscribed area of FIGURE 1, well 22 is located at the center of the area. Located at the midpoint of each of the lines describing the circumscribed area are wells 23, 24, 25, and 30. Located at the four corners formed by the intersections of the four lines describing the circumscribed area are wells 31, 32, 33, and 34, respectively.

In the first step of the process, displacing fluid is injected into central well 22. In this first step, petroleum oil is produced from wells 23, 24, 25, and 30. Thus, these wells are operated as production wells. Additionally, in the first step, wells 31, 32, 33, and 34 are shut in.

The displacing fluid injected into well 22 passes through the petroleum reservoir underlying the field into the direction of wells 23, 24, 25, and 30. The pathways of the displacing fluid migrating from the well 22 to any one of the wells 23, 24, 25, and 30 are affected by the presence of the wells to each other. Many of these pathways are curvilinear and, thus, portions of the reservoir other than those in a direct line between well 22 and any one of wells 23, 24, 25, and 30 are swept by the displacing fluid. With continued injection of the displacing fluid into well 22, breakthrough of the displacing fluid into each of wells 23, 24, 25, and 30 eventually occurs.

With breakthrough of the displacing fluid into each of the four production wells, the shape of the area swept by the displacing fluid, i.e., the sweep pattern, will be as indicated in FIGURE 3. This sweep pattern is the dark area 35 within the circumscribed area 21. The ratio of the area 35 to the area 21 varies with the mobility ratio, i.e., the mobility of the displacing fluid to the mobility of the displaced fluid. Mobility is defined as the ratio of the permeability of the reservoir to the fluid and the viscosity of the fluid. With a mobility ratio of 1:1, the area 35 will constitute 45.5 percent of the area 21. Thus, with the well pattern illustrated in FIGURE 1, the area swept by the first step of the process

with a mobility ratio of 1:1, 45.5 percent of the total area of the reservoir lying between the wells.

In the second step of the process, referring to FIGURE 2, displacing fluid is continued to be injected into central well **22**. Wells **23**, **24**, **25**, and **30** are shut in and wells **31**, **32**, **33**, and **34** are operated as production wells. The production wells are now located at the intersections of the lines describing the circumscribed area **21**.

The displacing fluid passes through the formation from the injection well into the direction of the new production wells. Petroleum is produced from each of the production wells and eventually breakthrough of the displacing fluid occurs at each of the production wells. The pathways of the displacing fluid migrating through the formation are affected by the location of the injection and the production wells and many of the pathways are accordingly curvilinear. The sweep pattern at breakthrough following the second step of the process is as indicated in FIGURE 4.

Referring to FIGURE 4, the sweep pattern is the dark area **40**. The major portion of the circumscribed area **21** is included within the area **40**. The ratio of the area **40** to the area **21** will depend upon the mobility ratio. With a mobility ratio of 1:1, the area **40** will constitute 83 percent of the area **21**. Thus, with the well pattern illustrated in FIGURES 1 and 2, the total area swept by the procedure of the invention for a mobility ratio of 1:1 will be 83 percent of the total area of the reservoir lying between the wells.

Another well pattern is illustrated in FIGURE 5. Field **41** overlies a petroleum reservoir and, similarly as with field **20**, is provided with a plurality of wells. These wells in field **41** are also arranged in a regular, geometric, uniform pattern. Further, each well is located at the corner of a hexagon. The pattern of the wells may also be described as being such that any one well, a central well, is surrounded by six wells equidistantly spaced from each other.

Well **42** lies in the center of circumscribed area **43**. Located at the intersections of the six lines describing the circumscribed area are wells **44**, **45**, **50**, **51**, **52**, and **53**, respectively. In the first step of the process, displacing fluid is injected into central well **42**. Petroleum is produced from wells **45**, **51**, and **53** and, thus, these wells are operated as production wells. Wells **44**, **50**, and **52** are shut in during this first step. The pathways of travel of the displacing fluid are, as previously described, affected by the various wells and many of the pathways are curvilinear. At breakthrough of the displacing fluid into production wells **45**, **51**, and **53**, the sweep pattern is as illustrated in FIGURE 7. The sweep pattern is the dark area **54** within the circumscribed area **43**. For a mobility ratio of 1:1, the area **54** will constitute 53 percent of the circumscribed area **43**.

In the second step of the process, referring to FIGURE 6, displacing fluid is continued to be injected into central well **42**. Wells **45**, **51**, and **53** are shut in and wells **44**, **50**, and **52** are operated as production wells. The displacing fluid passes through the formation from the injection well into the direction of the new production wells and eventually breakthrough of the displacing fluid occurs at each of the production wells. Many of the pathways of travel of the displacing fluid are curvilinear as previously explained and at breakthrough of the displacing fluid into all of the production wells, the sweep pattern is as illustrated in FIGURE 8. The sweep pattern is the dark area **55** within the circumscribed area **43**. The sweep pattern will constitute, for a mobility ratio of 1:1, 81 percent of the circumscribed area **43**.

The procedure of the invention is applicable to any type of production operation for petroleum oil where a displacing fluid is injected into the oil-containing formation. Among these procedures are gas drive, water drive, miscible flooding, and in-situ combustion. In gas drive operations, a gas such as a flue gas, carbon dioxide, natural gas, or other gas is injected into the formation into an injection well. This gas displaces the petroleum oil as it advances through the formation and forces the oil through the formation into the direction of the production wells. In water drive operations, water is injected into the formation through an injection well and the injected water displaces petroleum oil from the formation and drives it through the formation to the production wells. In miscible flooding, a material is injected into the formation through an injection well to form a fluid phase in the formation and thereafter a driving gas is injected into the formation. The material injected into the formation is one which is miscible with the petroleum oil in the formation and the driving gas is one which is miscible with the material forming the fluid phase. The driving gas forces the fluid phase through the formation into the direction of the production wells and the advancing fluid phase displaces the petroleum oil from the formation and drives it into the direction of the output wells. In in-situ combustion, a combustion-supporting gas is injected into the formation through an injection well and combustion of petroleum oil within the formation is initiated. With continued injection of the combustion-supporting gas, a flame front advances through the formation consuming a portion of the petroleum oil in the formation and displacing the remainder from the formation and forcing it into the direction of the production wells. Various combinations of these procedures may be employed. For example, gas and water may be employed as the displacing fluid. Water may be used in connection with a miscible flooding procedure. Water may also be employed in conjunction with an in-situ combustion operation.

In the practice of the invention, it is not necessary that all the wells required to carry out both steps be provided at the time the first step is carried out. Those wells not employed in the first step need not be provided until the second step is carried out. Thus, wells **31**, **32**, **33**, and **34** of FIGURE 1 and wells **44**, **50**, and **52** of FIGURE 5 need not be provided while the first step is carried out. During the time that the first step is being carried out, or after the final step has been carried out, these wells may be drilled and the second step thereafter carried out.

Having thus described my invention, it will be understood that such description has been given by way of illustration and example and not by way of limitation, reference for the latter purpose being had to the appended claims.

I claim:

1. A process for the recovery of liquid material from a subterranean formation penetrated by an even number at least as great as six of production wells each of which is equidistantly spaced from each of the two nearest adjacent production wells and positioned in a geometric pattern having an input well at its midpoint comprising injecting into said input well a fluid capable of displacing said liquid material contained within said subterranean formation, producing liquid material contained within said subterranean formation from a first production means comprising only every other one of said production wells which are equally spaced from said input well a distance not greater than the distance between each of the remainder of said production wells and said input well until said displacing fluid arrives at said production wells from which said liquid material has been produced, closing off said production wells from which said liquid material has been produced, continuing to inject into said input well a fluid capable of displacing said liquid material contained within said subterranean formation, and producing liquid material contained within said subter-

ranean formation from a second production means comprising the remainder of said production wells.

2. The process of claim 1 wherein said production wells are arranged in a square surrounding said input well.

3. The process of claim 1 wherein said production wells are arranged in a hexagon surrounding said input well.

4. A process for the recovery of liquid material from a subterranean formation comprising injecting into an input well penetrating said formation a fluid capable of displacing said liquid material contained within said subterranean formation, producing liquid material contained within said subterranean formation from a first production means comprising only at least three production wells each of which is equidistantly spaced from each of the two nearest adjacent production wells and equidistantly spaced from said input well until said displacing fluid arrives at each of said production wells, closing off said production wells in said first production means, thereafter continuing to inject into said input well a fluid capable of displacing said liquid material contained within said subterranean formation, and producing liquid material within said subterranean formation from a second production means comprising the same number of production wells as in said first production means, each of said production wells in said second production means being equidistantly spaced from each of the two nearest adjacent production wells in said second production means, equidistantly spaced from each of the two nearest adjacent production wells in said first production means, and equally spaced from said input well a distance at least as great as the distance between each of said production wells in said first production means and said input well.

5. A process for the recovery of liquid material from a subterranean formation comprising drilling a well as an input well from the surface of the earth to said formation, drilling an even number of production wells at least as great as six from the surface of the earth to said formation, each of said wells being equidistantly spaced from each of the two nearest adjacent production wells and positioned in a geometric pattern having said input well at its midpoint, injecting into said input well a fluid capable of displacing said liquid material contained within said subterranean formation, producing liquid material contained within said subterranean formation from a first production means comprising only every other one of said production wells which are equally spaced from said input well a distance not greater than the distance between each of the remainder of said production wells and said input well until said displacing fluid arrives at said production wells in said first production means, closing off said production wells in said first production means, continuing to inject into said input well a fluid capable of displacing said liquid material contained within said subterranean formation, and producing liquid material contained within said subterranean formation from a second production means comprising the remainder of said production wells.

6. A process for the recovery of liquid material from a subterranean formation comprising drilling an input means comprising an input well from the surface of the earth to said formation, drilling a first production means comprising at least three production wells from the surface of the earth to said formation, each of said production wells being equidistantly spaced from each of the two nearest adjacent production wells and equidistantly spaced from said input well, injecting into said input well a fluid capable of displacing said liquid material contained within said subterranean formation, producing liquid material contained within said subterranean formation from each of said production wells in said first production means until said displacing fluid arrives at said production wells, closing off said production wells in said first production means, drilling a second production means comprising the same number of production wells as in said first production means, each of said production wells in said second production means being equidistantly spaced from each of the two nearest adjacent production wells in said second production means, equidistantly spaced from each of the two nearest adjacent production wells in said first production means, and equally spaced from said input well a distance at least as great as the distance between each of said production wells in said first production means and said input well, injecting into said input well a fluid capable of displacing liquid material contained within said subterranean formation, and producing liquid material contained within said subterranean formation from each of said production wells in said second production means.

7. The process of claim 6 wherein said production wells are arranged in a square surrounding said input well.

8. The process of claim 6 wherein said production wells are arranged in a hexagon surrounding said input well.

9. A process for the recovery of liquid material from a subterranean formation penetrated by a central well surrounded by eight peripheral wells arranged in a square with said central well at the midpoint of said square and four of said peripheral wells each being located at the intersection of the lines describing said square and four of said peripheral wells being located at the midpoints of the lines describing said square, comprising closing said wells located at the intersections of the lines describing said square, injecting into said central well a fluid capable of displacing said liquid material contained within said subterranean formation, producing said liquid material contained within said subterranean formation from each of said four peripheral wells located at the midpoints of the lines describing said square until said displacing fluid arrives at said peripheral wells, closing off each of said peripheral wells located at the midpoints of the lines describing said square, opening said four peripheral wells located at the intersections of the lines describing said square, continuing injection into said central well of a fluid capable of displacing said liquid material contained within said subterranean formation, and producing said liquid material contained within said subterranean formation from each of said four peripheral wells located at the intersections of the lines describing said square.

10. A process for the recovery of liquid material from a subterranean formation comprising drilling a well from the surface of the earth to said formation, drilling four peripheral wells arranged in a square with said first-named well at the midpoint of said square and each of said peripheral wells being located at the midpoints of the lines describing said square, injecting into said first-named well a fluid capable of displacing said liquid material contained within said subterranean formation, producing said liquid material contained within said subterranean formation from each of said four peripheral wells until said displacing fluid arrives at said peripheral wells, closing off said peripheral wells, drilling four peripheral wells each at the intersections of the lines describing said square, injecting into said first-named well a fluid capable of displacing said liquid material contained within said subterranean formation, and producing said liquid material contained within said subterranean formation from said last-named four peripheral wells.

11. In a method of recovering hydrocarbons from a hydrocarbon-bearing formation that is substantially devoid of natural fluid energy having a plurality of wells arranged substantially in regular spaced rows penetrating said formation, said wells further defining a number of 9-

spot patterns each pattern consisting of 3 rows of 3 wells and describing a square wherein the middle well of each row in each direction is equidistant from the other two wells thereof, and employing a system in which said hydrocarbons are displaced from said formation by injection into the central well of at least one 9-spot pattern a displacing fluid, the improvement which comprises: producing the displaced hydrocarbons only from the four wells closest to and surrounding said input well until said displacing fluid breaks through to said four closest wells; closing in said four closest wells; and then producing said displaced hydrocarbons only from the four wells next closest and surrounding said input well while continuing to force displacing fluid into the input well, thereby substantially reducing any islands of unproduced hydrocarbons.

References Cited by the Examiner

UNITED STATES PATENTS

1,826,371	10/31	Spindler	166—9
2,347,778	5/44	Heath	166—2
2,885,002	5/59	Jenks	166—9

OTHER REFERENCES

Herold, S. C.: "Some Analytical Principles in Recovery by Force Drive," Oil and Gas Journal, Oct. 28, 1926, pp. 118, 171–174.

Fagin, K. M.: "Effect of Well Spacing on Water Flood Operations and Economics," The Petroleum Engineer, June 1946, pp. 64–72.

CHARLES E. O'CONNELL, *Primary Examiner.*

BENJAMIN BENDETT, *Examiner.*