

[72] Inventors **James E. Marberry**
Calgary, Alberta, Canada;
Henry C. Coutret, Jr, Shreveport, La.
 [21] Appl. No. **799,177**
 [22] Filed **Feb. 14, 1969**
 [45] Patented **Mar. 30, 1971**
 [73] Assignee **Mobil Oil Corporation**

3,193,009 7/1965 Wallace et al. 166/272
 3,353,598 11/1967 Smith 166/245
 3,421,583 1/1969 Koons 166/269
 3,477,510 11/1969 Spillette 166/272

Primary Examiner—Stephen J. Novosad

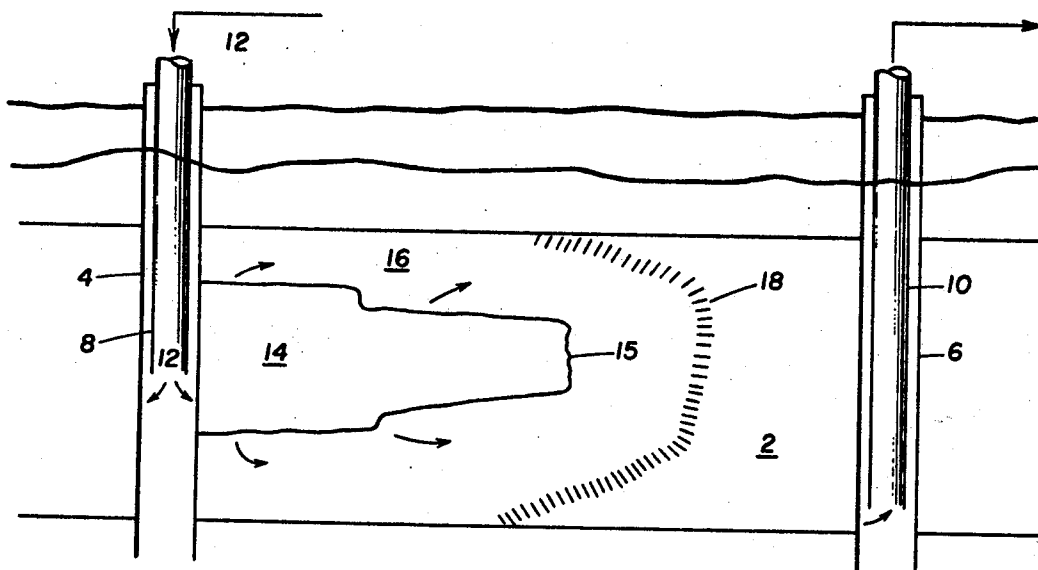
Attorneys—William J. Scherback, Frederick E. Dumoulin,
 William D. Jackson, Andrew L. Gaboriault and Sidney A.
 Johnson

[54] **OIL RECOVERY BY STEAM INJECTION
 FOLLOWED BY HOT WATER**
 13 Claims, 2 Drawing Figs.

[52] U.S. Cl. 166/272
 [51] Int. Cl. E21b 43/24
 [50] Field of Search 166/272,
 273, 274

[56] **References Cited**
UNITED STATES PATENTS
 3,042,114 7/1962 Willman 166/272

ABSTRACT: This specification discloses methods of recovering oil from subsurface oil reservoirs penetrated by at least an injection and a production well. Steam is injected into the reservoir to form a steam zone intermediate the injection and production wells. Subsequently hot water at the same temperature as the injected steam is injected into the reservoir to fill the steam zone. Thereafter cold water is injected into the reservoir to drive the hot water toward the production well and oil is recovered from the reservoir via the production well.



OIL RECOVERY BY STEAM INJECTION FOLLOWED BY HOT WATER

BACKGROUND OF THE INVENTION

This invention relates to a thermal method of recovering oil from a subsurface oil reservoir. More particularly, this invention relates to a method of recovering oil from a subsurface oil reservoir wherein steam is injected into the reservoir through at least one injection well and oil is produced therefrom through at least one production well.

Oil recovery from reservoirs is normally characterized either as primary recovery or secondary recovery. Primary recovery utilizes the naturally occurring forces within the reservoir to force the oil from the formation into production wells. These naturally occurring forces include: (1) the expanding force of high-pressure gas, (2) the buoyant force of encroaching water, and (3) the force of gravity. Secondary recovery utilizes forces applied from extraneous energy sources to supplement the naturally occurring forces in the reservoir to produce oil therefrom. These secondary forces may result from, for example, gas injection, steam injection, water injection or in situ combustion. It is not necessary that the primary forces of the reservoir be exhausted before secondary recovery be initiated. In fact, good reservoir engineering practices many times dictate that secondary recovery be begun early in the primary recovery cycle though this is sometimes called pressure maintenance rather than secondary recovery.

The amount of oil recovered by primary means usually varies from 10 to 50 percent of the original oil in place with 15 to 40 percent recovery being normal. Therefore more oil usually remains in the reservoir as unrecoverable by primary means than is produced therefrom. Secondary recovery is thus extremely important in its application of recovering a portion of this otherwise unrecoverable oil.

A high-pressure steam drive is an example of a secondary recovery process which is utilized in the recovery of oil. Such a steam drive process is described in U.S. Pat. No. 3,353,598, to R. V. Smith. A depleted reservoir containing a pattern of injection and production wells is first waterflooded. The waterflood is then terminated and steam is injected into the reservoir. Thereafter steam injection is terminated and water at normal reservoir temperature is injected into the reservoir to drive the steam and heat through the well pattern to the production wells. The injection of water at normal reservoir temperature effects steam condensation at the interface of the water and steam, thereby avoiding later condensation of steam behind the driving front or water-steam interface. Another steam drive process is described in U.S. Pat. No. 3,360,045, to M. Santourian. This process is concerned with stratum blocking that results when steam is injected into a reservoir containing heavy crude oil. By this process, a hot, nonaqueous gas is first driven through a horizontal zone of the stratum between an injection and a production well. Steam is then injected into the reservoir for a substantial period of time. Subsequently, it is preferred to follow the steam with a waterflood drive. The waterflood may utilize water at atmospheric temperature or hot water, the latter being preferred.

SUMMARY OF THE INVENTION

In accordance with the present invention there is provided a method for recovering oil from a subsurface oil reservoir penetrated by at least an injection and a production well. Steam is injected into the reservoir to form a steam zone intermediate the injection and production wells. Thereafter, hot water at the same temperature as the injected steam is injected into the reservoir in an amount sufficient to fill the steam zone with this hot water. Oil is recovered from the reservoir through the production well. In a preferred embodiment of the invention cold water then is injected into the reservoir to drive the hot water through the reservoir toward the production well thus further aiding in the recovery of oil from the reservoir.

Another preferred embodiment of this invention is directed to recovering oil from a subsurface oil reservoir penetrated by a pattern of injection and production wells. Steam is injected through a first injection well into the reservoir to form a steam zone intermediate the first injection well and one or more production wells. Subsequently, hot water of the same temperature as the injected steam is injected through the first injection well into the reservoir in an amount sufficient to fill this first steam zone. Upon filling the steam zone, hot water injection is terminated and cold water is injected through the first injection well into the reservoir to move the hot water toward the production well. This process is repeated by selectively using a second injection well and a production well which may be the same as or different from the production well used in conjunction with the first injection well.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical section of an oil reservoir penetrated by an injection and production well and illustrates a steam zone formed intermediate the wells; and

FIG. 2 is a plan view illustrating a normal five-spot pattern located within the outlines of an oil reservoir.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention is directed to a secondary recovery process for recovering oil from a subsurface oil reservoir penetrated by at least an injection well and a production well. Steam is injected into the reservoir to form a steam zone intermediate the injection and production wells. Thereafter an amount of hot water at the same temperature as the injected steam is injected into the reservoir until the steam zone is filled with this hot water. By injecting hot water of the same temperature as the steam into the steam zone rather than simply terminating steam injection or injecting cold water into steam zone, collapse of the steam zone is prevented. The injection of cold water into the steam zone or simply terminating steam injection would result in rapid condensation of the steam and collapse of the steam zone. Such a collapse would result in a lower pressure or pressure sink in the former steam zone and would draw back into this zone oil which had previously been swept therefrom.

Preferably after hot water injection is terminated, cold water is injected as a driving fluid into the reservoir to drive the hot water and heat zone formed from the steam and hot water through the reservoir toward the production well. The heat of the steam and hot water is thereby efficiently utilized in recovering oil from the reservoir.

More particularly and with reference to FIG. 1, there is shown a subsurface oil reservoir 2 which is penetrated by an injection well 4 and a production well 6. The injection well 4 is equipped with tubing 8 for the injection of fluids into the reservoir. Production well 6 is equipped with tubing 10 for the production of fluids from the reservoir. Steam 12 from surface equipment (not shown) is injected through tubing 8 into reservoir 2 to form a steam zone 14 intermediate the injection and production wells. Subsequently, hot water at the same temperature as the injected steam is injected through tubing 8 into reservoir 2 to fill steam zone 14. During the process oil is recovered from reservoir 2 through tubing 10 of production well 6. Subsequent to the injection of hot water into reservoir 2 cold water may be injected into the reservoir to move the hot water toward the production well and further facilitate oil recovery from the reservoir through tubing 10 of production well 6. The term "cold water" is used in a comparative sense to mean water at a temperature significantly less than the injected steam temperature. Normally the injected cold water will be at ambient temperature, e.g., a temperature in the range of 40° F. to 90° F.

Steam zone 14 is characterized by the existence of a positive steam saturation. The steam saturation need only be sufficient to permit vapor to flow within it. Such a steam saturation is on the order of 10 to 14 percent. The remainder of the pore space

within the steam zone is filled with water and residual oil. The residual oil saturation is relatively low, typically on the order of 5 to 15 percent. The water in the steam zone is comprised of water originally present in the reservoir, water formed by partial condensation of the steam, and water injected into the reservoir along with steam. The vapor and liquid within the steam zone are in thermal equilibrium. Thus, the temperature of the steam zone is determined by the pressure within it. The pressure decreases in the steam zone 14 in going from injection well 4 toward production well 6. Thus the temperature also decreases toward production well 6. Much of the pressure drop and consequent temperature decrease occurs in the immediate vicinity of injection well 4. The remainder of steam zone 14 is at a relatively constant temperature which is somewhat lower than the injection temperature.

As steam 12 is injected into reservoir 2, steam zone 14 is formed having a steam front 15 as the lead boundary. Steam flows through steam zone 14 to steam front 15 where it condenses to form hot condensate which flows away from the front. As the steam front moves past a point in the reservoir the oil saturation is reduced to a relatively low value as a result of several mechanisms. Just ahead of the front, the hot condensate begins heating the reservoir rock and fluids contained there by conduction and convection. The boundary between the heated and unheated rock is indicated by boundary 18. The effect of heating the oil is to decrease the viscosity of the oil and improve the oil mobility ratio. Thermal expansion of the oil also occurs, thereby displacing a further small amount of oil. Movement of the steam front through this preheated portion of the reservoir causes a further reduction in the oil saturation through a multiphase flow (gas drive) effect. Behind the steam front in the steam zone through which steam is flowing the process of steam stripping takes place. Little or no liquid oil flow takes place in the steam zone. The stripping process volatilizes the lighter components of the oil and reduces the oil saturation to its final low value. The volatilized light components flow with the steam to the steam front where both materials condense. The light components dilute the oil just ahead of the steam front and thus form a solvent drive or light oil bank which adds to the effectiveness of the other mechanisms in reducing the oil saturation.

The steam zone 14 is formed and maintained as the result of steam injection into reservoir 2. With the start of steam injection condensation begins immediately as the steam contacts the cool rock of the reservoir. Condensation continues at the boundary of the steam zone while this zone exists. Thus, condensation of steam takes place at the upper and lower surfaces of the steam zone and reduces the quantity of steam which arrives at steam front 15. A hot water zone 16 is thus formed surrounding steam zone 14. The hot water in hot water zone 16 essentially flows parallel to the steam flow toward production well 6.

This invention is directed to a steam injection secondary recovery process which increases the amount of oil recovered from a reservoir per unit volume of injected steam. An amount of steam is injected which contains sufficient heat to efficiently produce the oil present within a selected pattern of the reservoir. In injecting this steam a steam zone is formed intermediate the injection and production wells. Preferably steam is injected in an amount less than that resulting in breakthrough of the steam into the production well. In most reservoirs this amount of steam forms a steam zone which has an areal sweep within the range of 40 to 60 percent of the areal sweep of a steam zone which would exist at breakthrough of steam into the production well. In most reservoirs the preferred amount of steam injected into the reservoir varies within the range of 0.25 to 1.0 pore volume measured as water. After the steam zone has been formed an amount of hot water at the same temperature as the steam is injected into the reservoir to fill the steam zone. This injection of hot water into the steam zone prevents collapse of the steam zone and formation of a pressure sink, thereby preventing oil which has been swept from the steam zone from being drawn back into it. An

increased amount of oil recovery per unit volume of injected steam is thus achieved.

The preferred quality of the steam injected into the reservoir varies within the range of 60 to 90 percent with 80 percent being preferred. The amount of heat contained by steam increases with the quality of the steam up to 100 percent quality, i.e., saturated steam. However, with the waters available for producing steam in an oil field, it is difficult to get higher than about 80 percent quality steam without severe depositional problems within the steam generating equipment. Therefore, 80 percent quality steam is normally used in carrying out the invention.

Subsequent to steam injection into the reservoir, hot water at the same temperature as the injected steam is injected into reservoir 2 in an amount sufficient to fill steam zone 14. Normally in most reservoirs the amount of hot water to be injected into the reservoir to fill the steam zone varies within the range of 0.02 to 0.03 pore volume. Oil is produced from reservoir 2 through production well 6 during the steam injection and hot water injection steps described above. Further, in a preferred embodiment of the invention, cold water is injected into reservoir 2 subsequent to termination of hot water injection in an amount sufficient to displace the hot water within the reservoir into production well 6. The amount of cold water injected is at least 0.60 pore volume and in most reservoirs normally falls within the range of 0.60 to 1.2 pore volumes.

For reasons previously given the hot water injected into the reservoir should be at the same temperature as the injected steam to prevent collapse of the steam zone and a resulting pressure sink within the reservoir. Preferably the hot water injected into the reservoir contains steam in an amount of 5 percent or less. This small amount of steam will ensure that the hot water is at exactly the same temperature as the previously injected steam. While some latitude can be allowed in the temperature equivalency between the hot water and the previously injected steam, a difference of only a few degrees Fahrenheit will result in some condensation in the steam zone with an attendant reduction in pressure. While this can be tolerated in carrying out the present invention, it is preferred that the hot water be at exactly the same temperature as the previously injected steam. This hot water may be supplied simply by applying a sufficient amount of heat to water to raise the temperature to that of the injected steam. On practical way to supply this hot water is by continuing to utilize surface steam generating equipment but apply only enough heat to the boiler water to produce a fluid which is 5 percent or less quality steam. Another practical means of supplying the hot water for injection into the injection well is to continue injecting 80 percent quality steam from surface steam generating equipment into the injection well and to mix a stream of cold water with the steam in an amount such that the stream of steam and water reaching the reservoir is hot water containing 5 percent or less steam.

The hot water may be injected into the reservoir at a rate commensurate with the capabilities of the hot water generating equipment and the capabilities of the injection well in the particular reservoir. However, it is preferred that the hot water be injected at a rate at least as great as the steam injection rate, measured as liquid. This further minimizes the pressure decline at the steam front during fill-up of the steam zone. A still further preferred embodiment of this invention concerns recovering oil from a subsurface oil reservoir penetrated by a multiplicity of injection wells and one or more production wells. Steam is injected through a first injection well into the reservoir to form a first steam zone intermediate the first injection well and a production well. Subsequently, hot water of the same temperature as the injected steam is injected into the reservoir through the first injection well in an amount sufficient to fill the first steam zone with hot water. Cold water then is injected through the first injection well into the reservoir to move the hot water toward the production well. Upon terminating steam injection in the first injection well after forming the first steam zone, steam is injected into a second

injection well into the reservoir to form a second steam zone intermediate the second injection well and a production well, which well may be the same as or different from the production well used in conjunction with the first injection well. Subsequently, hot water at the same temperature as the injected steam is injected via the second injection well into the reservoir to fill the second steam zone with hot water. Thereafter, cold water is injected via the second injection well into the reservoir to move the hot water of the second steam zone toward the production well.

This preferred embodiment of the invention is best described by reference to the normal five-spot pattern of FIG. 2. Wells 21, 22, 23, and 24 are injection wells and well 25 is a production well. Steam is first injected via injection well 21 to form a first steam zone 26 intermediate injection well 21 and production well 25. Preferably steam zone 26 is formed by injecting 0.25 to 1.0 pore volume of 60 to 90 percent quality steam measured as water into injection well 21. Thereafter hot water at the same temperature as the injected steam is injected via injection well 21 into the pattern in an amount sufficient to fill the first steam zone 26. The amount of hot water injected desirably is within the range of 0.02 to 0.03 pore volume. This normally will ensure that the steam zone is filled with hot water. Thereafter, cold water is injected via injection well 21 into the pattern to displace the hot water toward production well 25. Preferably cold water in the amount of at least 0.60 pore volume is injected through the injection well into the reservoir. Subsequent to the injection of steam into the injection well 21 steam is injected via injection well 22 into the pattern to form a second steam zone 28 intermediate injection well 22 and production well 25. Again, about 0.25 to about 1.0 pore volume of 60 to 90 percent quality steam measured as water may be injected via injection well 22 to form second steam zone 28. Thereafter, hot water in the amount of 0.02 to 0.03 pore volume may be injected via injection well 22 to fill the second steam zone. Subsequently at least 0.60 pore volume of cold water is injected via injection well 22 to move the hot water toward production well 25. This procedure is then repeated utilizing injection well 23 and production well 25 and thereafter utilizing injection well 24 and production well 25.

While this invention has been described with particular reference to the normal five-spot pattern of FIG. 2, it is of course understood that it is applicable to other patterns as well. For example, it may be employed in a direct line drive wherein injection wells are formed in a line and production wells are formed in another line with each injection well being directly offset by a production well. In such a direct line drive there is realized the nearest approach to a complete vertical planar advance of the flooding medium. A modification of the direct line drive is the staggered line drive wherein production wells are diagonally offset from injection wells. A developed five-spot pattern is a case of the staggered line drive wherein the distance between all like wells is constant.

In addition, this invention is applicable with normal four-spot, seven-spot, and nine-spot patterns. The normal four-spot pattern employs three injection wells surrounding one production well; a normal seven-spot pattern employs six injection wells surrounding a production well; and a normal nine-spot pattern consists of eight injection wells surrounding one production well. This invention is further applicable to inverted patterns. For example, it is applicable to an inverted nine-spot pattern which has eight production wells that surround on injection well.

As used herein "pore volume" means pattern pore volume or, in other words, the pore space within a reservoir encompassed by a particular pattern. Pore volume is normally expressed in accordance with equation (1) below:

$$P.V. = A \times h \times \Phi \quad (1)$$

where:

P.V. = pattern pore volume of the reservoir;
A = area of the pattern;

h = thickness of the reservoir; and
 Φ = porosity of the reservoir.

In case of a two-well pattern consisting of an injection and a production well, the pattern is generally considered elliptical in shape. In such a two-well pattern the area A may be calculated by squaring the distance between injection and production wells.

We claim:

1. A method of recovering oil from a subsurface oil reservoir penetrated by an injection well and a production well, comprising the steps of:
 - a. injecting steam via said injection well into said reservoir to form a steam zone intermediate said injection well and said production well;
 - b. subsequently injecting hot water via said injection well into said reservoir in an amount sufficient to fill said steam zone, said hot water being at the same temperature as said injected steam of step (a); and
 - c. recovering oil from said reservoir through said production well.
2. A method of recovering oil from a subsurface oil reservoir penetrated by an injection well and a production well, comprising the steps of:
 - a. injecting steam via said injection well into said reservoir to form a steam zone intermediate said injection well and said production well;
 - b. subsequently injecting hot water via said injection well into said reservoir in an amount sufficient to fill said steam zone, said hot water being at the same temperature as said injected steam of step (a);
 - c. subsequently injecting cold water via said injection well into said reservoir to move said hot water toward said production well; and
 - d. recovering oil from said reservoir through said production well.
3. The method of claim 2 wherein said injected steam is of a quality within the range of 60 to 90 percent.
4. The method of claim 2 wherein said injected hot water contains steam in an amount of not more than 5 percent.
5. The method of claim 2 wherein said hot water is injected at a rate at least as great as the steam injection rate.
6. A method of recovering oil from a subsurface oil reservoir penetrated by an injection well and a production well, comprising the steps of:
 - a. injecting steam via said injection well into said reservoir to form a steam zone having an areal sweep of a size less than the size of the areal sweep which would exist at steam breakthrough into said production well;
 - b. subsequently injecting hot water via said injection well into said reservoir in an amount sufficient to fill said steam zone, said hot water being at the same temperature as said injected steam of step (a);
 - c. injecting cold water via said injection well into said reservoir to move said hot water toward said production well; and
 - d. producing oil from said reservoir through said production well.
7. The method of claim 6 wherein said areal sweep of said steam zone is within the range of 40 to 60 percent of the areal sweep of a steam zone which would exist at breakthrough of steam into said production well.
8. A method of recovering oil from a subsurface oil reservoir penetrated by an injection well and a production well, comprising the steps of:
 - a. injecting through said injection well into said reservoir 0.25 to 1.0 pore volume of 60 to 90 percent quality steam thereby forming a steam zone intermediate said injection well and said production well;
 - b. subsequently injecting into said reservoir through said injection well 0.02 to 0.03 pore volume of hot water of the same temperature as said injected steam of step (a) thereby filling said steam zone with hot water;
 - c. subsequently injecting into said reservoir through said injection well at least 0.60 pore volume of cold water; and

- d. recovering oil from said reservoir through said production well.
9. A method of recovering oil from a subsurface oil reservoir penetrated by a multiplicity of injection wells and production wells, comprising:
- a. injecting steam through a first injection well into said reservoir to form a first steam zone intermediate said first injection well and a production well;
 - b. subsequent to step (a) injecting through said first injection well hot water of the same temperature as said injected steam into said reservoir in an amount sufficient to fill said first steam zone with said hot water;
 - c. subsequent to step (b) injecting cold water through said first injection well into said reservoir to move said hot water toward said production well;
 - d. subsequent to step (b) injecting steam through a second injection well into said reservoir to form a second steam zone intermediate said second injection well and a production well;
 - e. subsequent to step (d) injecting hot water at the same temperature as said injected steam into said oil reservoir to fill said second steam zone with said hot water; and
 - f. subsequent to step (e) injecting cold water through said second injection well into said oil reservoir to move said hot water in said second steam zone toward said production well.

10. The method of claim 9 wherein 0.25 to 1.0 pore volume of 60 to 90 percent quality steam is injected through each of said first and second injection wells.

11. The method of claim 10 wherein 0.02 to 0.03 pore volume of hot water at the same temperature as said injected steam is injected through each of said first and second injection wells.

12. The method of claim 11 wherein at least 0.60 pore volume of cold water is injected through each of said first and second injection wells.

13. A method of recovering oil from a subsurface oil reservoir penetrated by an injection well and a production well, comprising the steps of:

- a. injecting steam via said injection well into said reservoir to form a steam zone having an areal sweep within the range of 40 to 60 percent of the areal sweep of a steam zone which would exist at breakthrough of steam into said production well;
- b. subsequently injecting hot water via said injection well into said reservoir in an amount sufficient to fill said steam zone, said hot water being at the same temperature as said injected steam of step (a); and
- c. recovering oil from said reservoir through said production well.

30

35

40

45

50

55

60

65

70

75