METHOD OF RECOVERING HYDROCARBON FLUIDS FROM A SUTERANEAN FORMATION

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ABSTRACT OF THE DISCLOSURE

A method of producing hydrocarbon fluids from a subterranean formation containing crude oil, particularly a viscous type crude oil. The method contemplates the combination of steam drives and an in-situ combustion wherein the steam drives are performed in lower portions of the formation to heat the formation with the in-situ combustions in upper portions of the formation to assist gravity in causing the oil to flow downwardly and into a producing well. The method also contemplates the spacing of the production wells in a polygonal pattern, with a steam injection well in the center thereof and an air injection along one side thereof.

This invention relates to a method of producing hydrocarbons from a subterranean formation containing a viscous type crude oil, which method utilizes both a steam drive technique and an in-situ combustion technique, combination with a particular spacing.

Many methods have been suggested for recovering low gravity viscous type crude oils, including such processes as steam injection or in-situ combustion. Both processes are involved in crude oil reservoirs, but both have limited applications by themselves in such heavy oil reservoirs as the Athabasca Tar Sands in Canada. Steam injection has proved successful in the tar sands, but the time necessary to successfully exploit the tar makes this process limited. In-situ combustion has proved workable in tar sands, but the lack of permeability and plugging results in inefficient oxygen utilization. It is also desirable to have a spotting pattern for the wells to give the most efficient coverage and utilization of steam and combustion.

It is therefore an object of this invention to provide a method of recovering heavy viscous oils from a hydrocarbon bearing formation, such as oil-bearing sands, or shale, wherein the oil is a gravity of 16° API or less. More specifically, the invention has application to the production of oil from oil bearing reservoirs containing oil 1,000 cp, or greater, (measured at standard temperature and pressure).

Briefly stated, the method of this invention contemplates drilling a plurality of production wells downwardly to bottom portions of a formation containing crude oil, with the pattern for the production wells being in the form of a plurality of equilateral polygons having an even number of sides. The invention also includes drilling a plurality of steam injection wells spaced apart from the production wells and extending downwardly to bottom portions of the formation, with each of the steam injection wells being spaced in the center of one of the polygons. It also includes drilling a plurality of air injection wells spaced apart from the steam injection wells and production wells and extending into top portions of the formation, with each of the air injection wells being spaced substantially equal distances between two of the production wells and on a line forming a side of one of the polygons. Forward steam injection is performed through the bottom portion of the formation from the steam injection wells to the production wells. In-situ combustion is started in the injection wells in top portions of the formation, which combustions are continued by supplying air under pressure through the air injection wells, whereby the heat of the steam injection, gravity pressure, combustion pressure, and heat causes the hydrocarbon fluids in the oil to flow toward the production wells. Thereafter, the fluid hydrocarbons are produced from the production well.

In certain embodiments of the method, it may be necessary to fracture the formation near the bottom thereof prior to the aforesaid steam injection step and this fracturing may be carried out by conventional manners such that the fracture extends between the first injection well and the production well.

In certain embodiments of the invention, and prior to said forward injection of steam, it may be necessary to first cyclically inject steam alternately in a steam injection well and a production well, and alternately producing the steam injection well and the production well after each steam injection. These alternate steam injection and production steps may be continued until there is communication between the steam injection well and the production well through the formation, whereby the aforesaid forward steam injection step may be carried out.

It is desirable to heat the formation to at least 200° F. In certain instances, it may be necessary to heat the formation to as high as 300° F., depending upon the viscosity of the oil which is being produced.

Reference to the drawings will further explain the invention wherein:

FIG. 1 shows an ideal well pattern for a virgin reservoir, with the production wells designated by small circles, steam injection wells designated by small squares, and air injection wells designated by small triangles, and in which the production wells form a pattern in the shape of an equilateral polygon in the form of a hexagon.

FIG. 2 is a schematic side elevation view of a production well, a steam injection well and an air injection well drilled into the formation containing the oil to be produced.

FIG. 3 shows an alternate pattern for the wells, which pattern might be used in connection with a producing reservoir.

FIG. 4 shows still another well pattern which may be used under some conditions.

Referring now to FIGS. 1 and 2, the method for carrying out the present invention in a virgin reservoir will first be explained. Since, in a virgin reservoir, there has been no prior spacing of any production wells, then the pattern shown in FIG. 1 is preferable because of the economy and coverage provided by the particular pattern shown. In other words, the production wells, designated by the numeral 11, are drilled in a pattern in the form of an equilateral polygon, preferably a hexagon. In the development of the field at least one of the hexagons will have each of its sides as a common boundary for an adjacent hexagon. Production wells 11 are drilled to lower portions of formation 12 as shown in FIG. 2.

Steam injection wells, designated by the numeral 13, are also drilled to extend downward to bottom portions of the formation 12, with each of the steam injection wells being spotted in the center of one of the polygons. Steam is forwardly injected from steam injection wells 13 to production wells 11 through the lower portions of formation 12. Depending on the permeability of the formation, it may be necessary to fracture the formation...
between production wells 11 and steam injection wells 13 before the forward steam injection can be carried out in certain instances. This fracturing may be carried out by conventional methods, as for example, by notching the casing in both wells at the point where the fracture is to be made and thereafter applying a fracturing fluid thereto in conventional manners, to thereby provide a fracture such as fracture 14, shown in FIG. 2, extending between a steam injection well and production well. It is to be understood that fracture 14 is located near the bottom of formation 12 to take full advantage of gravity drainage.

In certain instances, and prior to the forward injection of steam through the formation from wells 13 to wells 11, it may be necessary to first cyclically steam inject alternately in wells 13 and 11, and alternately produce wells 13 and 11 until there is communication between wells 13 and 11 through formation 12, as shown in FIG. 2.

The steam which is utilized for the forward steam injection is a conventional type and is generally high quality steam. The forward steam injection is continued until at least a portion of the formation is heated to at least about 200° F. and preferably at least about 300° F., depending upon the viscosity of the oil which is to be produced.

The heat of the steam moves upwardly through the formation, with convection and conduction, thereby rendering the oil less viscous and more free flowing, such that it may be carried out to production wells 11 along with the water of condensation.

When the forward steam injection has been carried on sufficiently to heat the formation to the desired temperature, in-situ combustions are started in the top portion of formation 12 by conventional means. Thereafter, pressurized air is supplied downwardly through wells 15 to sustain the combustions and to generate pressure which extends downwardly through the formation as schematically shown in FIG. 2. The air injection also assists in establishing gas permeability through production formation 12.

The heat and pressure created by the in-situ combustions in the top portion of the formation, combined with the heat and fluid flow provided by the steam injection step, plus gravity and thermal expansion, causes the hydrocarbon fluids in formation 12 to flow downwardly in the formation where they are carried to production wells 11 along with the water of condensation. The oil and water of condensation is thereafter produced from wells 11 by conventional means.

Field experience has indicated that 200° F. plus temperatures are necessary to have heavy oil sands or tar sands release their oil. The oil does not ordinarily become mobile until these temperatures are reached. Continued temperature increase thereafter does not necessarily produce more oil because the energy to drive the oil from the sand into the fracture is missing. Hence, the use of the in-situ combustion above the fracture in the sand accomplishes the desired result with a minimum of heating. With this combination of steps, the oil is more mobile and will not plug the formation.

The spacing of the wells is also important to provide the optimum number of wells to effectively cover a given area which is to be subjected to steam injection and air injection. In the usual development of thermal recovery projects in the past, a single well is tested first to ascertain whether the formation will take steam or air. Next, a pattern is drilled (usually a five-spot pattern) to pilot test the area. From this point on, if the pilot is successful, development is rapid and customarily follows the five-spot pattern. This five-spot pattern consists of an injection well and four producing wells spaced thereof. If steam or air injection alone is practiced, this is a satisfactory pattern. However, it is not the most effective pattern for real coverage, particularly if both air and steam injection are to be carried on concurrently, as described above.

In the pattern of the wells in FIG. 1, which pattern is best for a virgin reservoir, each steam injection well 13 can provide steam to six production wells which form the polygonal pattern, as shown above in FIG. 1. Each air injection well 15 provides an in-situ combustion extending to at least two adjacent production wells 11 and two adjacent steam injection wells 13 and form air injection patterns such as that shown as the shaded area designated by the numeral 17. Each air injection well 15 is spaced substantially equal distance between two production wells 11 and on a line forming a side of one of said polygons.

FIG. 3 shows an alternate pattern for the wells which might be used in an established producing field where the established pattern is shown in FIG. 1 and is designated by the numeral 20, with additional fill in production wells shown as black dots designated by the numeral 21. It will be noted that the production wells 20 and fill in wells 21 combine to form the aforesaid polygonal pattern. In the conventional development of fields and without the use of secondary recovery, wells 20 are normally drilled in straight rows, as shown in FIG. 3. When it becomes desirable to practice the method of the present invention, the fill in wells 21 are drilled along with steam injection wells 22 and air injection wells 23.

As with the prior embodiment in FIG. 2, each injection well 22 is drilled centrally in a hexagonal pattern formed by the production wells 20 and 21, and an air injection well 23 is drilled substantially equal distance between twp production wells 20 and on a line forming a side of a polygon. The result is that there is provided steam injection patterns such as that shown by the shaded area designated by the numeral 24 which is substantially the same as the steam injection patterns 17 shown in FIG. 1. Similarly, there are provided air injection patterns designated by the numeral 25 which correspond with air injection patterns 18 in FIG. 1. One disadvantage of this pattern over that described with respect to FIG. 1 is that no more than two sides of each hexagon form common boundaries with adjacent hexagons. The result is that there is provided what is some time referred to as a wasted diamond shaped area between the rows of hexagon patterns as shown, which areas are not fully covered by steam and air.

Referring now to FIG. 4, an alternate and somewhat less preferred pattern for the wells is shown wherein the pattern formed by the production wells is in the shape of a plurality of squares. This pattern might be used, for example, where it was not possible or desirable to use the hexagonal pattern for the production wells. In this embodiment, the production wells are designated by the numeral 29, the steam injection wells by the numeral 30 and the air injection wells by the numeral 31. A steam injection pattern for each steam injection well 30 is shown as a shaded area designated by the numeral 33, for example. Similarly, each air injection well 31 covers an air injection pattern such as that shown by shaded area designated by the numeral 34. This pattern is somewhat less efficient than the FIG. 3 embodiment and considerably less efficient that the FIG. 1 embodiment for the reason that fewer production wells are covered per steam injection well and air injection well.

Thus, the invention provides a novel method of producing a formation which combines the advantages of combustion and steam injection in combination with a very efficient spacing pattern to accomplish optimum recovery of otherwise unrecoverable viscous type oils.

Further modifications may be made in the invention as described without departing from the scope thereof. Accordingly, the foregoing description is to be construed as illustrative only and is not to be construed as a limitation upon the invention as defined in the following claims.

What is claimed is:

1. The method of producing fluid hydrocarbons from
a subterraneous formation containing crude oil, said method comprising in combination the steps of:
drilling a plurality of production wells downwardly to bottom portions of said formations, with the pattern for said production well being in the form of a plurality of equilateral polygons having an even number of sides;
drilling a plurality of steam injection wells spaced apart from said production wells and extending downwardly to bottom portions of said formations, with each of said steam injection wells being spotted in the center of one of said polygons;
drilling a plurality of air injection wells spaced apart from said steam injection wells and said production wells and extending downwardly into top portions of said formations, with each of said air injection wells being spotted substantially equal distance between two of said production wells and on a line forming a side of one of said polygons;
forward injecting steam through bottom portions of said formation from said steam injection wells to said production wells;
starting in-situ combustions in said air injection wells in top portions of said formations and continuing said in-situ combustions by supplying air under pressure through said air injection wells, to thereby create downward pressure on said oil in said formation, whereby the heat of said steam injection, gravity pressure, and combustion pressure causes the hydrocarbon fluids of said oil to flow toward said production wells;
and producing said fluid hydrocarbons from said production wells.

2. The method as claimed in claim 1 including:
fracturing said formation near the bottom thereof prior to injection of said steam.

3. The method as claimed in claim 1 including:
prior to said forward injecting of steam through said formation, first cyclically steam injecting alternatively in one of said steam injection well and one of said production well and alternatively producing said one steam injection well and said one production well after each steam injection;
continuing said cyclical steam injection and production steps until there is communication between said one steam injection well and said one production well through said formation.

4. The method as claimed in claim 1 including:
continuing said forward steam injection until at least a portion of said formation is heated to at least 300° F.

5. The invention as claimed in claim 1 wherein:
said polygons in said pattern are hexagons.

6. The invention as claimed in claim 5 wherein:
each side of at least one of said hexagons forms a common boundary of another hexagon.

7. The invention as claimed in claim 5 wherein:
no more than two sides of each hexagon form common boundaries with adjacent hexagons.

8. The invention as claimed in claim 1 wherein:
said polygons in said pattern are squares.

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