Nov. 4, 1969 J. C. ALLEN 3,476,182
METHOD OF HYDROCARBON PRODUCTION BY SECONDARY RECOVERY
USING A MODIFIED INVERTED 9-SPOT WELL PATTERN
Filed Aug. 17, 1967 2 Sheets-Sheet 1

Fig. 1.

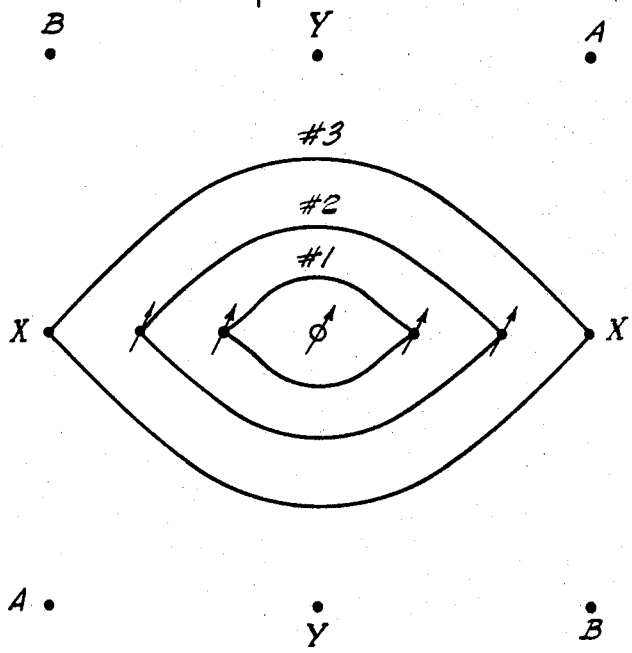


Fig. 2.

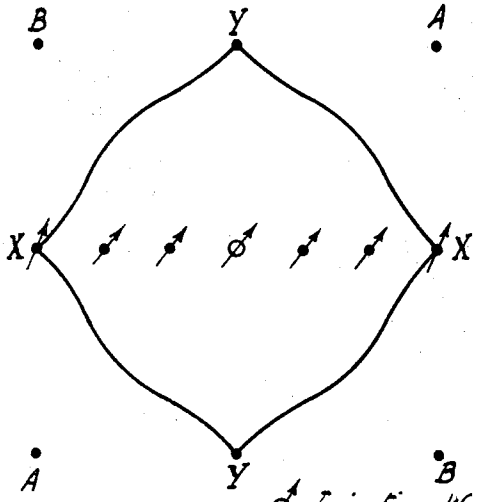
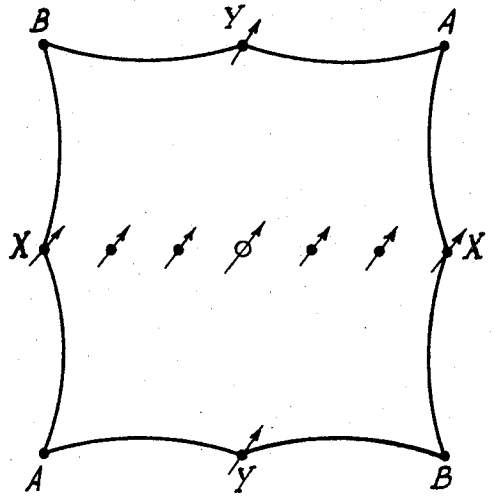


Fig. 3.



Injection Well
Production Well
Production Well Converted to Injection Well

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Fig. 4.

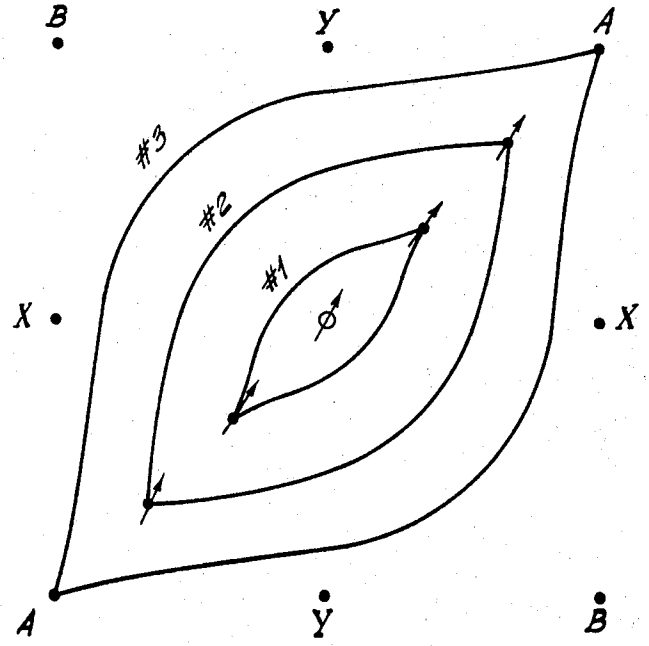


Fig. 5.

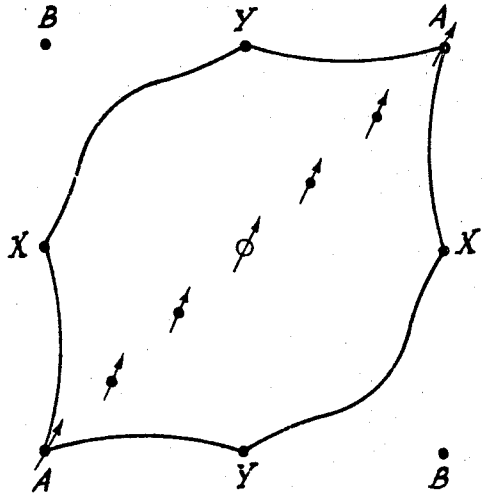
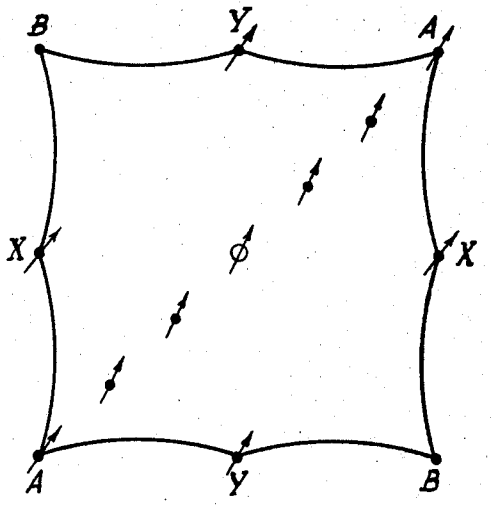


Fig. 6.



United States Patent Office 3,476,182
Patented Nov. 4, 1969

3,476,182

METHOD OF HYDROCARBON PRODUCTION BY SECONDARY RECOVERY USING A MODIFIED INVERTED 9-SPOT WELL PATTERN

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Filed Aug. 17, 1967, Ser. No. 661,322
Int. Cl. E21b 43/14, 43/24
U.S. Cl. 166—245 10 Claims

ABSTRACT OF THE DISCLOSURE

Well arrangement and procedure for performing a line drive in situ combustion operation wherein an inverted 9-spot pattern is modified by the addition of four production wells along either a lateral or diagonal axis within the pattern, the wells on the axis being converted to injection wells from production wells as the in situ combustion front reaches each in turn.

FIELD OF THE INVENTION

This invention relates generally to the production of hydrocarbons from underground hydrocarbon-bearing formations, and more particularly, to a method for increasing the overall recovery of hydrocarbons therefrom.

DESCRIPTION OF THE INVENTION

In the production of hydrocarbons from permeable underground hydrocarbon-bearing formations, it is customary to drill one or more boreholes or wells into the hydrocarbon-bearing formations and produce hydrocarbons, such as oil, through designated production wells, either by the natural formation pressure or by pumping the wells. Sooner or later, the flow of hydrocarbons diminishes and/or ceases, even though substantial quantities of hydrocarbons are still present in the underground formations.

Thus, secondary recovery programs are now an essential part of the overall planning for virtually every oil and gas-condensate reservoir in underground hydrocarbon-bearing formations. In general, this involves injecting an extraneous fluid, such as water or gas into the reservoir zone to drive the oil or gas toward production wells by the process frequently referred to as "flooding."

Another secondary recovery procedure employed for recovering the remaining hydrocarbons comprises the igniting and burning of hydrocarbons in situ within the permeable underground formations, whereby hot gases are generated to force hydrocarbons in the formation toward the production wells. While such in situ combustion has been quite successful in secondary recovery operations, it has been much less than one hundred percent efficient because the combustion front tends to progress through the formations along locally channeled paths from the area of injection to the production area, thus bypassing substantial volumes of the hydrocarbons in the formation, rather than sweeping the hydrocarbons as a bank from a broad area of the formation.

SUMMARY OF THE INVENTION

It is an overall object of the present invention to provide an improved in situ combustion procedure involving a modified 9-spot well pattern arrangement to produce almost all of the hydrocarbons remaining in place in the formation, by changing the function of the wells in the pattern at strategic times to gain maximum control of the fire front.

An inverted 9-spot well pattern arrangement, which may be a unit in a larger pattern of wells in a producing field, is modified by the addition of four production wells within the unit pattern and located on an axis through the original injection well and two original production wells. Twelve wells are put on production and the in situ combustion operation is initiated at the central well, proceeding until breakthrough occurs at the adjacent production wells. Upon breakthrough, these adjacent production wells are converted to air injection wells in the manner disclosed in the copending, co-assigned application for patent for Hydrocarbon Production by Secondary Recovery, Ser. No. 649,924, filed on June 29, 1967, by C. D. Woodward, the disclosure of which is incorporated herein by this reference, while the remaining wells continue on production. The changes from a production well to an air injection well after the combustion front breaks through are continued until all the wells on this axis have been converted from production to air injection wells. Then the procedure is repeated as the side wells of the pattern suffer breakthrough until the pattern is substantially swept clear upon breakthrough at the corner wells.

While this invention is applicable particularly to in situ combustion, it can be adapted readily to other forms of fluid drive for secondary recovery.

The objects, advantages and features of the invention will become apparent from a consideration of the specification in the light of the figures of the drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 discloses an inverted 9-spot well pattern arrangement which may be a unit in a larger pattern of wells in a producing field and which has been modified by the addition of four production wells within the unit pattern on the axis through the original central injection well and two original side production wells, showing how the combustion front breaks through along the line of axial wells;

FIG. 2 discloses the well arrangement of FIG. 1 during a later phase of the in situ combustion operation, illustrating the change in the combustion front at breakthrough at the other side production wells of the pattern arrangement during the line drive;

FIG. 3 shows a further change in the combustion front at the time of breakthrough at the corner production wells; and

FIGS. 4, 5 and 6 disclose a unit of a similarly modified 9-spot well pattern arrangement showing the manner in which the combustion front advances when the additional four production wells are located within the unit pattern on the axis through the original central injection well and the corner production wells, corresponding respectively to FIGS. 1, 2 and 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As disclosed herein, it is possible to change a single well drive operation into a line drive operation to substantially completely sweep an underground reservoir.

Referring now to the drawings, which schematically illustrate the practice and advantages of my invention, there are shown some of the operations observed in a secondary recovery program.

FIG. 1 discloses a unit of a modified 9-spot well pattern arrangement, which may be one of a number in a production field, operating as an inverted 9-spot pattern, the figure depicting the step advance of the combustion front as the function of each axial production well is changed to that of an injection well at breakthrough. The consecutive numbering of the burned out areas discloses the shapes of the combustion front as it progresses.

In the inverted 9-spot pattern, the corner and side wells of each pattern unit are production wells while the central well is used for injection. Throughout the figures of

the drawings, the same symbols will be maintained as follows: a single head arrowed circle to indicate an air injection well, a solid circle to indicate a production well, and a single head arrowed solid circle to indicate a production well converted to an air injection well. Also, the side production wells on the lateral axes passing through the central injection well are indicated as X, X and Y, Y, and the corner production wells on the diagonal axes passing through the central injection well are indicated as A, A and B, B.

FIG. 2 discloses the conversion of the pattern of FIG. 1 into a line drive, wherein all the production wells on the lateral axis through the original central injection well and the two side production wells have been converted into air injection wells, the other two side wells and the corner wells remain on production, or are put on production, until breakthrough occurs at the other two side production wells. Thereupon, these latter side production wells are converted to air injection wells and production at the corner wells is continued until breakthrough thereat, as disclosed symbolically in FIG. 3.

In the above cited copending application for patent, results of a test in a South Texas reservoir are disclosed.

This experiment demonstrated that a production well which has been overtaken by a thermal reaction zone can be converted to an air injection well and the burn successfully sustained and advanced in the reservoir. Thus, a line drive can be established in a field by a sequence of production and injection at given wells. During this same test, initially the burn migrated in a uniform manner from the injection well but later severe cusping toward the production well occurred, resulting in a less than satisfactory burn. This test for a 2-well pilot pattern indicated that a fifty foot spacing between the injection and production wells was too small. A later test in the same field involving a double, inverted 10-acre, 5-spot pattern was very successful, the distance between injection and production wells being 330 feet. In still a later line drive operation in the same field, a less than satisfactory result was achieved with the lines of injection and production wells being 660 feet apart. Also, for a line drive, the spacing between injection and production wells should be at least three times the distance between adjacent injection wells. These and other considerations lead to a distance of 300 feet between injection and production wells and would dictate a spacing of about 100 feet or less between adjacent injection wells. This is the set-up of the arrangement of the well pattern in FIG. 1. To be sure that the reaction from injection wells is continuous, so as not to leave unburned areas or islands, the central well is ignited first and the other injection wells are converted from production wells as they become "hot" producers.

FIGS. 4, 5 and 6 disclose the different shapes of the flame front when the additional production wells are located within the unit pattern on the diagonal axis through the original air injection wells and two of the original corner production wells, the changes in function from production to air injection wells following the same steps as disclosed in FIGS. 1, 2 and 3, as the original production wells become "hot" producers.

Alternatively (not shown), the operations disclosed in FIGS. 1 and 4 could be completed without production from the corner or other two side production wells and then only the corner wells could be put on production until breakthrough thereat, followed by a change in the function of the corner wells to air injection wells and placing the other two side wells on production until breakthrough thereat.

Thus, it has been shown and described how a pattern drive may be converted into a line drive to more completely sweep a production field.

Obviously, other modifications and variations of the invention, as hereinbefore set forth, may be made without departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. A method of producing hydrocarbons from an underground hydrocarbon bearing formation via an inverted 9-spot well pattern modified by the addition of four production wells within said pattern on an axis through the injection well which comprises:

(a) initiating an in situ combustion at said injection well while producing fluids including hydrocarbons from said formation via the axial production wells until breakthrough of the combustion front occurs at a production well immediately adjacent said injection well,

(b) thereupon converting the production well suffering breakthrough of said combustion front to an injection well while continuing producing fluids including hydrocarbons from the remaining axial production wells and also converting the same to injection wells as breakthroughs occur until all said axial wells are injection wells, and

(c) thereupon producing fluids including hydrocarbons from the remaining production wells of the pattern until breakthrough of the combustion front occurs thereat, converting the last mentioned production wells to the injection wells as the combustion front breaks through thereat.

2. A process for recovering hydrocarbons by in situ combustion from a gas pervious underground hydrocarbon-bearing formation by exploitation through a well pattern wherein a central well is located within a ring of a plurality of diametrically positioned wells defining a quadrilateral and additional wells located along an axis through said central well and within said quadrilateral comprising:

(a) injecting air into said central well and initiating in situ combustion of hydrocarbons thereat, thereby forming a high temperature combustion front moving away from said central well,

(b) simultaneously producing fluids including hydrocarbons from said formation via said diametrically positioned and axial wells until said high temperature combustion front breaks through at one of said wells, and

(c) ceasing producing fluids at the production well where said combustion front has broken through and converting the same to an air injection well while producing fluids including hydrocarbons from the remaining production wells until breakthrough of said front at another production well, thereupon converting said last mentioned production well to an air injection well and continuing the production of fluids including hydrocarbons from said formation until complete exploitation thereof.

3. A process in accordance with claim 2, wherein said well pattern is a 9-spot well pattern modified by the addition of four production wells within this unit pattern on an axis through the central well located within a much larger pattern of wells in a producing field, and wherein said steps are applied to a series of adjoining wells arranged in a series of such well patterns within said larger pattern.

4. A method of producing hydrocarbons from an underground hydrocarbon-bearing formation involving an injection well and at least a pair of production wells adjacent each other, these three wells being in line and penetrating into said formation as part of an inverted 9-spot well pattern modified by the addition of four additional production wells within said pattern and located on an axis of said pattern passing through said injection well, said pair of production wells being included among said additional production wells, comprising introducing a driving fluid into said formation via said injection well, producing fluids including hydrocarbons from said formation via the production well closer to said injection well

and maintaining producing thereof therefrom until said driving fluid begins to appear at the aforesaid closer production well and thereupon ceasing producing fluids therefrom and commencing introducing said driving fluid thereinto and also producing fluids including hydrocarbons via the other of said production wells until breakthrough of said driving fluid thereat.

5. In a method of producing hydrocarbons as defined in claim 4, said wells being included in a pattern of wells in a producing field, the steps of consecutively converting a production well which has signs of a driving fluid to an injection well until said producing field has been exploited.

6. In a method of producing hydrocarbons as defined in claim 4, the lateral axes of said pattern being spaced approximately three times the distance between adjacent wells used for injection, the last mentioned spacing being about 100 feet.

7. In a method of producing hydrocarbons as defined in claim 4, said axis being a lateral axis through the original injection well and two of the original side production wells.

8. In a method of producing hydrocarbons as defined in claim 4, said axis being a diagonal axis through the original injection well and two of the original corner production wells.

9. A method of producing hydrocarbons from an underground hydrocarbon-bearing formation involving a centrally located injection well surrounded by production wells located at the vertices, on the sides and on an axis of a quadrilateral, said wells on said axis being within said quadrilateral, said axis passing through said injection well, which comprises introducing a combustion supporting fluid into said formation via said injection well and initiating in situ combustion thereat, producing fluids including hydrocarbons from said formation via the production wells defining said quadrilateral and on said axis until breakthrough of the combustion front occurs at one of said production wells on said axis, thereupon ceasing producing fluids including hydrocarbons from said production well where said breakthrough of said combustion front has occurred and converting said last mentioned production well into an injection well for said combustion supporting fluid, and continuing producing fluids including hydrocarbons from said production wells and converting each of said production wells on said axis to an injection well when breakthrough of the combustion front occurs thereat until all the production wells on said axis have been converted to injection wells.

10. In the method of producing hydrocarbons as defined in claim 9, the additional steps of respectively ceasing producing fluids including hydrocarbons upon breakthrough of said driving fluid at a production well and converting the same to an injection well until said hydrocarbon-bearing formation has been swept clean.

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