Oct. 14, 1969 C. D. WOODWARD 3,472,318

HYDROCARBON PRODUCTION BY SECONDARY RECOVERY

Filed June 29, 1967

Fig. 1.

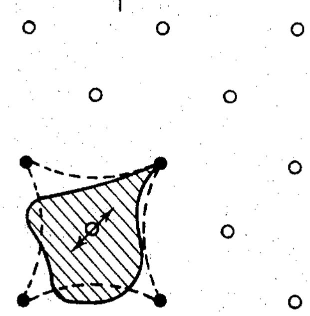


Fig. 2.

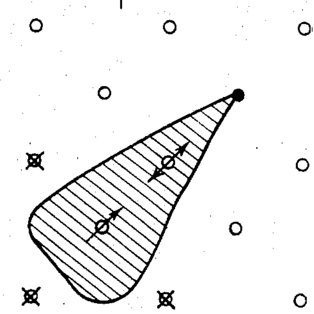


Fig. 3.

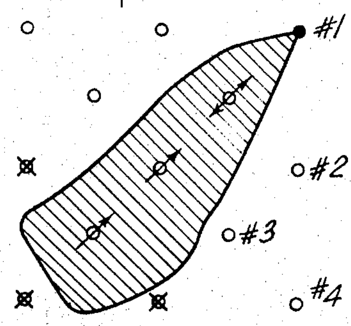


Fig. 4.

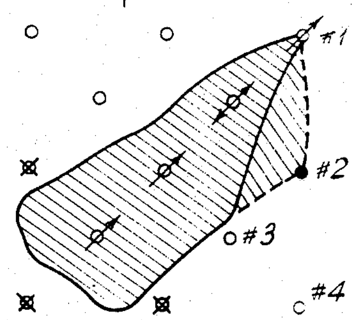


Fig. 5.

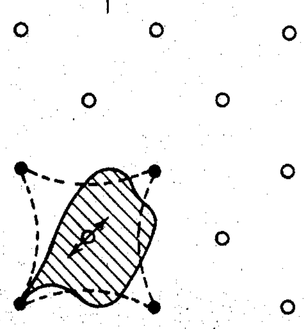


Fig. 5a.

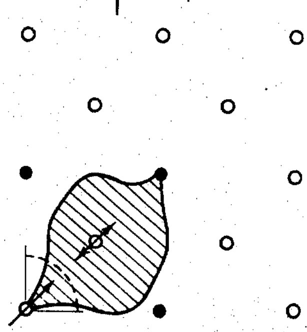


Fig. 6.

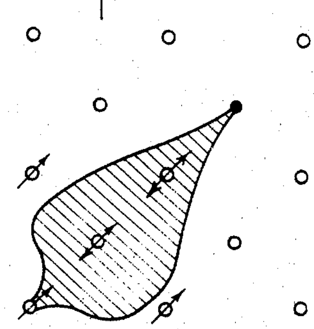
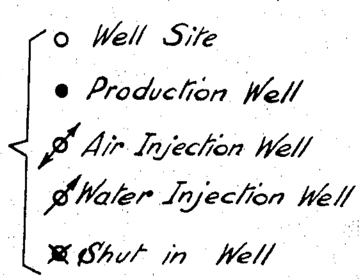


Fig. 7.



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HYDROCARBON PRODUCTION BY SECONDARY RECOVERY

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ABSTRACT OF THE DISCLOSURE

Conversion of a pattern pilot drive to a single well line drive to sweep a production field by a meandering drive is disclosed, along with the prevention of reinvasion from adjoining unexploited areas. This is accomplished during a direct in situ combustion operation initiated in an inverted 5-spot pattern by changing the function of a production well, whereat breakthrough has occurred, to that of an injection well, and initiating production at a selected well of an adjoining pattern unit to continue the in situ combustion. Production at the other wells of the original pattern unit may be contained till breakthrough and then/or used as produced water disposal wells to prevent reinvasion, and the original injection well is converted to a water disposal well also, thus maintaining a pressure gradient in the original pattern unit. These changes in function can be followed consecutively as the in situ combustion operation proceeds through the pattern units of a production field.

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 production 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 essention 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 initially a 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 five-spot pattern initiates the in situ combustion operation and proceeds until breakthrough occurs at one of the production wells. Upon breakthrough, this production well is converted to an air injection well, the original air injection well is converted to a water injection well for receiving the produced water, and the remaining pattern wells are put on a standby basis, either being shut in completely or used for produced water disposal, while production is initiated at a well adjacent the recently converted production to air injection well.

While this invention is applicable particularly to in situ combustion, it can be adapted readily to other forms of fluid drive for second 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 four units of a five-spot pattern well arrangement, the third quadrant unit operating as an inverted five-spot pattern;

FIGS. 2 and 3 disclose the well arrangement of FIG. 1 during a later phase of the in situ combustion operation, illustrating the change from a well pattern drive to a single well drive;

FIG. 4 shows a further change to a single well meandering operation;

FIGS. 5, *5a* and 6 disclose also four units of a five-spot pattern well arrangement showing the manner in which the direction of a pattern drive can be controlled by means of the conversion of production wells to injection wells;

FIG. 7 is a grouping of symbols used throughout the drawing.

Description of the preferred embodiment

As disclosed herein, it is possible to change a pattern pilot operation into a single well drive operating in a meandering fashion to substantially completely sweep an underground reservoir.

Referring now to the drawing, which schematically illustrates the practice and advantages of my invention, there are illustrated a pair of operations observed in secondary recovery operations.

FIG. 1 discloses four units of a five-spot pattern well arrangement, wherein the third quadrant unit is operating as an inverted five-spot pattern, the figure depicting in dotted outlines an ideal burnt out area for the inverted five-spot pattern, while the cross hatching indicates the actual burnt out area at breakthrough at one of the interior wells of the pattern.

In the inverted five-spot pattern, the corner wells of each pattern unit are production wells while the central well is used for injection. Throughout the figures of the drawing, the same symbols will be maintained as follows: the open circle to indicate a well site, a solid circle to indicate a production well, a crossed circle to indicate a shut in well, a single head arrowed circle to indicate a water injection well, and a double head arrowed circle to indicate an air injection well.

FIG. 2 discloses the conversion of the pattern pilot of FIG. 1 into a single well drive, wherein the production well at breakthrough in FIG. 1 now has been converted into an air injection well, the former air injection well is now a water injection well to receive the water produced from the underground formation, and an interior well of the five-spot pattern adjacent the production well on breakthrough in FIG. 1 has been put on production. This well has been selected for production assuming that the drive is toward the northeast, but any of the other well sites could be chosen to direct the pattern flood in that direction, as will be developed further.

FIG. 3 discloses a later state of the production drive patterns of FIGS. 1 and 2, wherein the single well drive is meandering toward the northeast to the corner well indicated as No. **1**, the production well at breakthrough in FIG. 2 having been converted to an air injection well, the former air injection well to a water injection well, while the water injection well of FIG. 2 is indicated as remaining so, although it could be closed in as are the corner wells of the original pattern.

Upon breakthrough of the fire flood at well No. **1**, as indicated in FIG. 3, production can be initiated at either wells Nos. **2** and **3** or at any other of the adjacent well sites, depending on the direction of choice. In FIG. 4, the production well at breakthrough at No. **1** is converted to a water injection well to prevent reinvasion while the previously functioning air injection well of FIG. 3 remains so and the two water injection wells maintain their same function. If production at well No. **2** has been chosen, then the additional sweepout area indicated by the different angled cross hatching would result. Upon breakthrough of the fire flood at either wells Nos. **2** or **3**, depending on the choice for production, then these wells could be converted to air injection wells in the manner disclosed basically in FIG. 2 and a drive commenced towards the newly selected production well, e.g. No. **4**, to complete the sweepout in the first three quadrants of the pattern. In the same manner, the sweepout of the fourth quadrant pattern can be completed. Alternatively, the pattern of FIG. 3 can be applied along parallel diagonals of a five-spot pattern production field.

Although in FIGS. 2, 3 and 4, the former production wells of FIG. 1 are shown as shut in, they are classified as stand-by for either water injection, if necessary to control the pattern as will be discussed below, or they could be maintained on production until breakthrough occurs thereat and converted to water injection wells to prevent reinvasion of the pattern from adjacent areas not yet swept out.

Tests were made to observe the principles disclosed above in a reservoir in south Texas, the reservoir data being substantially as follows:

Depth ____ft__	1575
Average net sand thickness ____ft__	18
Porosity ____percent__	32.7
Oil saturation ____do__	38.0
Permeability to air, md. ____	1610
API gravity ____	20.9
Bottom hole temperature, ° F. ____	110

An air injection well was drilled between two existing wells, one a former producer and another a former water injection well. Service installations were made, these latter two wells were equipped as principal producers, and air receptivity was established at the air injection well. Ignition of the in place crude was accomplished with spontaneous ignition chemicals. During the life of the experiment, lease oil production more than doubled in the four months after ignition and at the termination of the project, the former producer well was pumping and flowing under normal operating conditions at a rate better than fifteen times the settled production rate prior to ignition. Combustion gas showed up at most of the wells on the leases sometime during the project, with the closest production wells being affected to a greater degree. Five months after ignition, a test well was drilled behind the reaction zone, showing the entire vertical section as burned substantially clean, the rate of advance of the reaction zone being in excess of 0.5 ft./day.

Eight months after ignition, the fire front arrived at the former producer well. This hot production well was shut in and converted to an air injection well to determine if the point of air injection could be moved while maintaining the combustion process. Gas analyses and gas production from surrounding wells indicated the burn was sustained and propagated during and after the change.

This experiment demonstarted 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 single well line drive can be established in a field by a sequence of production and injection at a given well, or alternatively, a field can be exploited by allowing the reaction zone to meander about in a reservoir with the abandoned air injection well available for water disposal and reinvasion control.

Referring now to FIGS. 5, *5a* and 6, there is shown how the disclosed invention can be used to control the direction of the drive considering different permeabilities of the reservoir. In FIG. 5, a pattern pilot has broken through at one of the production wells on the outside edge of a four unit, five-spot pattern in a direction opposite to that desired, e.g. toward the northeast quadrant. To alleviate the problem, the production well suffering breakthrough is now converted into a water injection well to continue the drive toward the other production wells of the pattern unit, until breakthrough is achieved in the desired direction. If breakthrough occurs at one of the boundary pattern production wells, then it too can be converted from a production well to a water injection well, as indicated in FIG. 6. In this figure, there is disclosed how the sweepout pattern of FIG. 5 has been controlled by changing the drive direction toward the northeast quadrant. In FIG. *5a*, the breakthrough well in production in FIG. 5 has been converted into a water injection well to prevent reinvasion from adjoining patterns and force the sweepout pattern in the opposite direction, with breakthrough occurring at an inside boundary production well. The function of this well is changed to an air injection well, the former air injection well in the center of the first five-spot pattern being exploited being converted into a water injection well, and production beginning at one of the wells adjacent the pattern in the direction desired. This pattern of FIG. 6 corresponds to that in FIG. 2 but differs therefrom by the conversion of the corner production wells of the pattern to a water injection well upon respective breakthroughs.

FIG. 7 is self explanatory and indicates the various symbols used in the preceding figures of the drawing.

Thus, it has been shown and described how a pattern pilot drive is converted into a single well line drive to sweep a production field by a meandering drive, preventing reinvasion from adjoining unexploited patterns and providing a solution for water disposal.

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 involving an injection well and a pair of wells immediately adjacent thereto and to each other and in line therewith and penetrating into said formation, at least one of said pair of wells being a production 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 well closer to said injection well and maintaining producing fluids therefrom until the front of said in situ combustion arrives thereat, thereupon, ceasing producing fluids therefrom and commencing introducing said combustion-supporting fluid thereinto and ceasing introducing said combustion-supporting fluid into said formation via said injection well and beginning the introducing of water into said formation via said aforementioned injection well while producing fluids including hydrocarbons via the other of said pair of wells until breakthrough of said front thereat.

2. In a method of producing hydrocarbons as defined in claim 1, said wells being included in a pattern of wells in a producing field, the steps of consecutively changing a production well at which said front appears to an injection well thereof, and converting an immediately preceding injection well for said combustion-supporting fluid into an injection well for water, said water being produced with said fluids including hydrocarbons from the production well.

3. In a method of producing hydrocarbons as defined in claim 2, said wells being part of a series of five-spot well patterns.

4. In a method of producing hydrocarbons as defined in claim 3, the steps of consecutively changing the functions of said wells being applied along parallel diagonals of the producing field pattern.

5. 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 of a quadrilateral and penetrating into said formation which comprises introducing a driving fluid into said formation via said injection well, producing fluids including hydrocarbons from said formation via the production wells defining said quadrilateral until breakthrough of said driving fluid occurs at one of said production wells, thereupon ceasing introducing said driving fluid into said formation via said injection well and producing fluids including hydrocarbons from said production well where said breakthrough of said driving fluid has occurred and converting said last mentioned production well into an injection well for said driving fluid, and initiating the producing of fluids including hydrocarbons from a well adjacent said injection well converted from said production well where said breakthrough of said injection fluid has occurred.

6. In the method of producing hydrocarbons as defined in claim 5, the step of converting the original injection well for driving fluid into an injection well for water, said water being produced with the fluids from the production wells.

7. In the method of producing hydrocarbons as defined in claim 6, 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, and initiating producing fluids including hydrocarbons from an adjacent well until said hydrocarbon-bearing formation has been swept clean.

8. A process for recovering hydrocarbons by in situ combustion from a gas pervious underground hydrocarbon-bearing formation by exploitation through a well pattern penetrating thereinto wherein a central well is located within a ring of a plurality of diametrically positioned wells comprising:

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

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

(c) ceasing producing fluids and thereafter commencing injecting water into the production well where said combustion front has broken through while continuing said in situ combustion of formation hydrocarbons and producing fluids including hydrocarbons from said remaining diametrically positioned wells until breakthrough of said front thereat, thereupon converting selected ones of said remaining wells to water injection wells and at least one of said remaining wells to an air injection well and initiating the production of fluids including hydrocarbons from a well adjacent said last mentioned well.

9. In the process as defined in claim 8, the additional step of

(d) injecting a pressurized fluid into said central well to maintain a pressure gradient outwardly from the zone burned out by in situ combustion whereby the air injection of step (c) is restricted to the hydrocarbon-bearing formation outside of said zone.

10. A process in accordance with claim 9 wherein said well pattern is a five-spot well pattern 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.

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U.S. Cl. X.R.

166—256, 2.63