United States Patent [19]

Strange

[11] **3,794,113**

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[54] **COMBINATION IN SITU COMBUSTION DISPLACEMENT AND STEAM STIMULATION OF PRODUCING WELLS**

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[51] **Int. Cl.** **E21b 43/24**

[58] **Field of Search** ... 166/245, 251, 252, 263, 256, 166/272, 261

[56] **References Cited**

UNITED STATES PATENTS

R27,252	12/1971	Sklar et al.	166/251
2,994,376	8/1961	Crawford et al.	166/245
3,153,448	10/1964	Dew et al.	166/245
3,272,261	9/1966	Morse	166/245
3,367,419	2/1968	Lookeren	166/245
3,441,083	4/1969	Fitzgerald	166/245
3,384,172	5/1968	Hujsak et al.	166/272
3,380,527	4/1968	Craighead	166/272
3,358,759	12/1967	Parker	166/263
3,707,189	12/1972	Prats	166/263

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[57] **ABSTRACT**

This specification discloses a method of producing hydrocarbons from a hydrocarbon-bearing formation penetrated by a pattern of wells including at least one injection well and two production wells spaced relatively close one to the other. The production wells are stimulated by heating the formation to form a heated zone about the production wells, for example, by injecting steam via the wells into the formation. A forward drive in situ combustion process is initiated at an injection well and production of hydrocarbons is initiated from the reservoir from at least one of the production wells. The heated zone is maintained by injecting heat, for example, steam, via another of the production wells while continuously producing hydrocarbons from at least one production well from within the heated zone. The producing wells are alternately employed for producing hydrocarbons from the formation and for injecting heat into the formation to maintain the heated zone about the producing wells.

6 Claims, 3 Drawing Figures

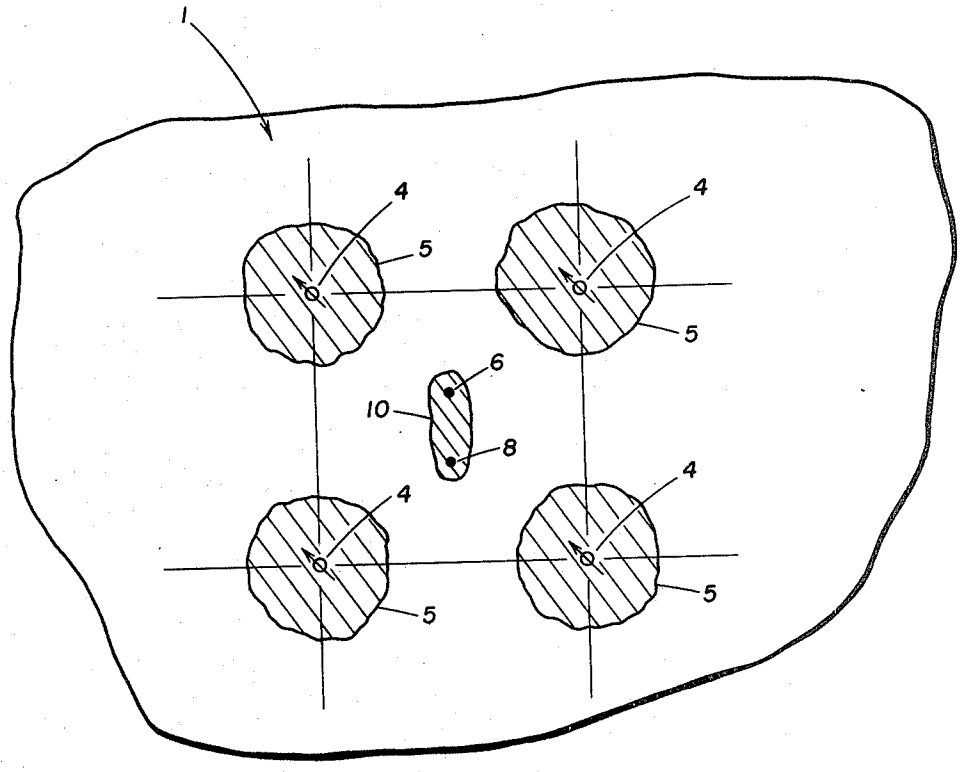


FIG. 1

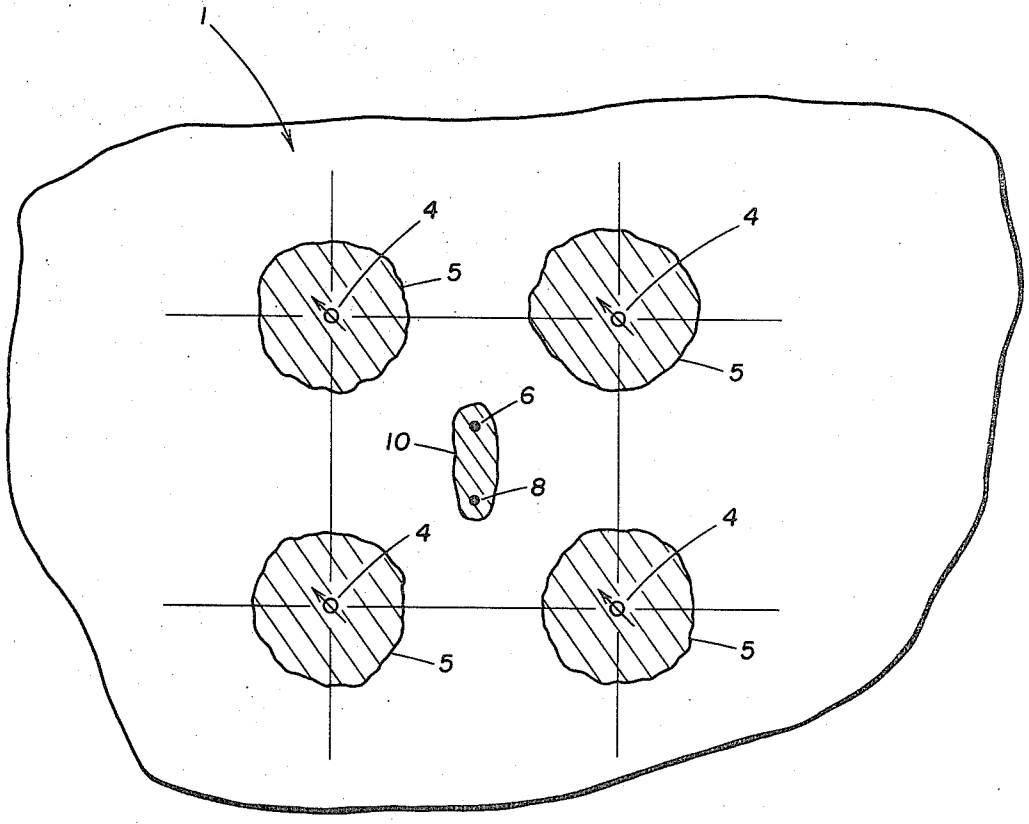


FIG. 2A

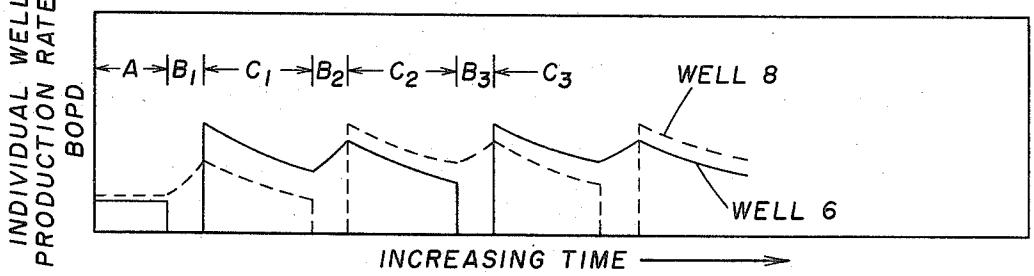
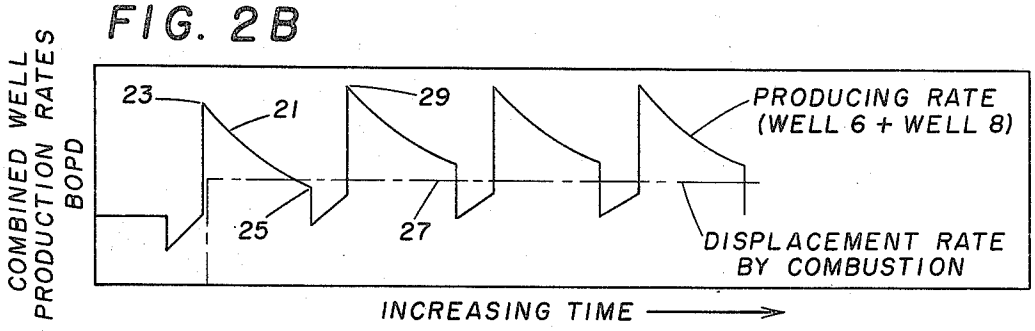

INDIVIDUAL WELL PRODUCTION RATES BOPD
A
B1
C1
B2
C2
B3
C3
WELL 8
WELL 6
INCREASING TIME

FIG. 2B


COMBINED WELL PRODUCTION RATES BOPD
23
21
29
25
27
PRODUCING RATE (WELL 6 + WELL 8)
DISPLACEMENT RATE BY COMBUSTION
INCREASING TIME

COMBINATION IN SITU COMBUSTION DISPLACEMENT AND STEAM STIMULATION OF PRODUCING WELLS

BACKGROUND OF THE INVENTION

This invention relates to an in situ combustion method of producing hydrocarbons from a hydrocarbon-bearing formation.

In situ combustion processes are particularly applicable for producing viscous hydrocarbons from hydrocarbon-bearing formations. In carrying out in situ combustion processes, air or other combustion-supporting gases are injected via injection wells into a hydrocarbon-bearing formation and heat is supplied to the formation to initiate combustion of the hydrocarbons contained therein. The combustion front is propagated through the formation and hydrocarbons are produced therefrom via production wells. In situ combustion processes are generally classified either as direct drive or inverse drive processes. In a direct drive in situ combustion process, a combustion front is initiated adjacent an injection well and propagated toward a production well by the controlled injection of a combustion-supporting gas into the injection well. In an inverse drive in situ combustion process, a combustion front is initiated adjacent a production well, and a combustion-supporting gas is injected into the formation via an injection well, causing the combustion front to be propagated through the formation from the production well toward the injection well.

Various problems are associated with both types of in situ combustion processes. In a direct drive in situ combustion process there is formed in front of the combustion front and relatively near the injection well a hot bank of hydrocarbons. The viscosity of this hot bank of hydrocarbons near the injection well is much less than the viscosity of the hydrocarbons existing in the remainder of the formation and near the production well. Thus, the capacity of the formation to flow hydrocarbons is much less near the production well than near the injection well. This results in a condition which is sometimes referred to as a "fluid blocking." When this condition occurs, flow of the lower viscosity hot bank of hydrocarbons near the injection well is retarded by the slower rate of flow of the higher viscosity hydrocarbons near the production well. Under severe conditions where highly viscous fluids are present in the formation the hydrocarbons near the production well may be relatively immobile and thus may to a large extent prevent the hot bank of hydrocarbons from flowing toward and into the production well. This results in a loss of efficiency and the hot bank of hydrocarbons may flow further from the production well and an excessive amount of the hydrocarbons may be burned in the formation.

Inverse drive in situ combustion processes have been employed to avoid the fluid blocking problems that are associated with direct drive in situ combustion processes. In inverse drive in situ combustion processes, the air or combustion-supporting gas that is injected into the formation via the injection well flows through the formation and carries the hydrocarbons that are heated by the combustion front through the combustion front and to the production wells where they are produced from the formation. This avoids the fluid blocking problems of direct drive processes. However, other problems are associated with the inverse in situ combustion processes. For example, the combustion front, in passing through the formation, removes most of the hydrocarbon material from that zone of the formation through which the front passes. Thereafter, as the heated hydrocarbons are moved through the combustion front toward the production wells they pass through this zone and are partially absorbed by the formation and thus not produced therefrom.

In U. S. Pat. No. 2,994,376 to Francis W. Crawford et al. there is described an inverse air in situ combustion process for recovering hydrocarbons from carbonaceous strata. A pattern of wells is drilled into the earth to penetrate a carbonaceous strata. This pattern includes a principal well which may serve as a production well and one or more auxiliary air injection wells drilled in the immediate vicinity of the principal well. One or more primary injection wells are drilled in a more remote location from the principal well. Air is injected via the auxiliary wells and combustion is initiated in the carbonaceous strata and driven by direct air drive toward the production well. Air may also be injected via the primary wells thereby causing the combustion front to move outwardly from the auxiliary wells countercurrently to the flow of air and thereby establishing a self-sustaining in situ combustion process.

In U. S. Pat. No. 3,379,246, reissued as U. S. Pat. No. Re. 27,252, to Isadore Sklar et al., there is described a direct drive in situ combustion process for producing hydrocarbons from a subterranean formation by moving therethrough an in situ combustion front between input and output wells. The directional movement and the rate of advance of the combustion front are adjusted by action taken relative only to the output wells. For this action there is injected into the formation from the output well means, while temporarily suspending production of any formation fluid therefrom, steam until a quantity of heat is injected into the formation surrounding the output well means. The output well means may be returned immediately to production after steam injection is terminated. However, it is preferred that it be shut in for a period of time.

In U. S. Pat. No. 3,272,261 to Richard A. Morse there is described a method of recovering viscous oils from subsurface oil-bearing formations. A heater well is drilled into the formation within the drainage area of a production well. Heat is injected into the formation at the heater well until the bottomhole temperature of the production well increases, and the rate of heat injection at the heater well is adjusted to maintain the bottomhole temperature at the production well in the range of about 200°–600° F., and oil is produced through the production well. Oil is driven through the formation by a drive fluid injected at an injection well and oil enters the heated zone around the heater well and, because of its reduced viscosity resulting from the heating, the oil flows readily to the production well.

SUMMARY OF THE INVENTION

This invention is directed to a method of producing hydrocarbons from a hydrocarbon-bearing formation penetrated by a pattern of wells including at least one injection well, a first production well and a second production well. A first production well and a second production well are provided to communicate with the hydrocarbon-bearing formation and are spaced laterally one from the other a distance of no more than

about 30 percent of the spacing between the injection and production wells. Steam is injected into the first production well and into the second production well to provide a heated region between the production wells. A forward in situ combustion drive is initiated from the injection well toward the first and second production wells and hydrocarbons are produced from the formation via the first production well while maintaining the heated zone by injecting steam into the second production well. Alternately hydrocarbons are produced from the formation via the second production well and steam is injected into the first production well to maintain the heated zone.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of a 5-spot pattern as employed in accordance with this invention.

FIG. 2A is a graph of individual well production rates versus time.

FIG. 2B is a graph of combined well production rates versus time.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention relates to an in situ combustion process for recovering hydrocarbons from a hydrocarbon-bearing formation, and more particularly relates to a direct drive in situ combustion process.

In accordance with this process, a pattern of wells is drilled and completed to communicate with a hydrocarbon-bearing formation. This pattern of wells includes at least one injection well and two production wells. The production wells are relatively closely spaced with respect to one another, the spacing normally varying, for example, from 50 feet to 200 feet, depending upon the spacing between injection and production wells. For example, the spacing between the production wells should normally be no more than about 30 percent of the spacing between the injection and production wells. In the case of a normal 20-acre 5-spot pattern the spacing between the injection and production wells is about 660 feet and thus the spacing between production wells would be no more than about 198 feet. A 20-acre pattern is about as large a pattern as would normally be used in producing heavy and highly viscous oils, though larger patterns could be used for producing lighter and less viscous oils. Heat is injected into the formation via the production wells to provide a heated region about these production wells. Heat is normally injected into the formation in the form of steam though other heated fluids may be used or heaters may be used to provide the heated region. A forward in situ combustion process is initiated in the injection well and concomitantly therewith production of hydrocarbons is initiated from the formation via at least one of the production wells. The heated zone about the production wells is maintained by injecting heat into the formation as needed via at least another of the closely spaced production wells. Alternately thereafter, production of hydrocarbons may be initiated from the other production well and the heated zone is maintained by injecting heat into the formation via the first production well. In accordance with this invention, once the production of hydrocarbons is initiated, this production is continuously carried out while maintaining a heated region about the production wells. A preferred method of injecting heat into the formation is by injecting a heated fluid, for example, steam, via the wells into the formation. In this process of continuously producing hydrocarbons from the formation, the heated region is maintained about the production wells without interrupting the production of hydrocarbons from the formation. This minimizes the alteration of pressure gradients which develop within the formation due to production of hydrocarbons from the pattern of wells communicating with the formation thereby better enabling the efficient use of large patterns.

This invention is applicable for use with any of the well patterns normally used in producing hydrocarbons from hydrocarbon-bearing formations. One such pattern is a 5-spot pattern and this invention is described in more detail with reference to a 5-spot pattern as illustrated in FIG. 1. In this figure, an areal portion of a hydrocarbon-bearing formation is represented by 1. The injection wells 4 and a first production well 6 and a second production well 8 are provided to communicate with the hydrocarbon-bearing formation. The injection and production wells may be drilled and completed in the formation by conventional techniques. The injection wells 4 are completed as in situ combustion injection wells and the production wells 6 and 8 are completed in a manner which enables them to be utilized both for the production of hydrocarbons from hydrocarbon-bearing formation and for the injection of heat into the formation. The 5-spot pattern employed in carrying out this invention utilizes two or more production wells rather than one production well as is employed in conventional 5-spot patterns. The provision of two or more production wells enables hydrocarbons to be continuously produced from the hydrocarbon-bearing formation while maintaining a heated zone about the production wells.

In carrying out an embodiment of this invention, steam is injected into the first production well 6 and the second production well 8 to provide a heated region or zone 10 about production wells 6 and 8. This heated zone is provided to extend between the production wells and preferably is of a sufficient size to provide a reasonably high total producing rate as compared with the total producing rate of the wells prior to the forming of this heated zone. Steam may be injected alternately into production well 6 and production well 8, or may be injected simultaneously into both of these wells in forming the heated zone 10. Steam may also be injected into injection wells 4 to steam stimulate these injection wells prior to the initiation of a combustion front within the hydrocarbon-bearing formation. The steam stimulation of the injection wells prior to the initiation of a combustion front about these wells provides the dual advantages of producing a quantity of flush oil and of increasing the heat level about the injection wells, thereby simplifying the later ignition of the combustion front. Air or other combustion-supporting gases are injected via injection wells 4 into the hydrocarbon-bearing formation and the injection wells are ignited to form a combustion front which provides a combustion heated zone 5 about injection wells 4. The combustion front is driven away from injection wells 4 and toward production wells 6 and 8 and production of hydrocarbons is continuously carried out through at least one production well. Steam is injected as needed into the producing wells to maintain the heated area 10 about the production wells 6 and 8 and to maintain a

total oil production rate equal to or greater than the calculated pattern displacement rate. By continuously producing hydrocarbons from the formation the alteration of the normal pressure gradients which develop within the pattern during production therefrom is minimized. The maintaining of these pressure gradients prevents the retardation of the movement of the burning front and prevents oil from being driven back into the previously burned region, thereby avoiding the consumption of an increased quantity of oil as fuel and the attendant requirement of an increased quantity of air to burn the fuel.

In selecting a production well into which to inject steam to maintain the heated region **10**, the production well that is producing at the lower rate is normally selected. This lower production rate indicates cooling of the formation about the well. Therefore, injecting steam into the production well having the lower production rate interferes least with the production of oil from the pattern.

When steam is injected into one of the production wells while the combustion front is being propagated toward the production wells, the steam will move primarily toward the other production well rather than interfering with the movement of the combustion front since the production well acts as a pressure sink. However, should there be a premature movement of the combustion front toward one of the production wells due to either operating or reservoir conditions which could result in premature combustion front breakthrough to the production well, it is desirable to preferentially inject steam into the well being approached by the front. This retards the preferential front movement of the combustion front toward that well and improves the overall pattern sweep efficiency and pattern oil recovery efficiency.

A more specific description is given to controlling the steam stimulation of a two-producing well pattern in a combustion recovery operation by reference to FIG. **2**. There is shown by FIG. 2A the individual oil producing rates for the two producing wells and there is shown in FIG. 2B the combined producing rates for the two wells and the rate at which oil is displaced by the combustion recovery process. These two producing wells may be the producing wells illustrated in FIG. **1** and are referred to as producing wells **6** and **8**.

In accordance with an embodiment of this invention, producing wells **6** and **8** are operated in different operating phases during time intervals designated generally as A, B, and C in FIGS. 2A and 2B. The producing wells **6** and **8** are operated as producers under unstimulated conditions during time interval A. Over an extended period of time there would be a decline in the production rates of wells **6** and **8** but this is not shown for time interval A. During time interval B the producing well having the lower producing rate is operated as a steam injection well while the other producing well is operated as a production well. At the end of time interval A, well **6**, which had the lower production rate during time interval A, is converted into and operated as a steam stimulation well during the time interval B_1. During time interval B_1, as shown by FIG. 2A, the production rate for well **6** is shown as **0**. The heat that is injected into well **6** effects an increase in the production rate of well **8**. During the time interval C_1 both wells **6** and **8** are operated as producing wells. The well **6** which was steam stimulated during time interval B_1 is shown to have a higher producing rate during time interval C_1. Both producing wells **6** and **8** are shown to have a general declining producing rate during time interval C_1 due to the loss of heat by conduction from the heated zone about the producing wells to formations and by convection with the hot liquids that are produced from the formation via wells **6** and **8**. The steam stimulation and production cycles are repeated as illustrated by time intervals B_2–C_2 and B_3–C_3.

In accordance with an embodiment, oil displacement by a combustion drive is initiated after steam stimulation has been commenced. In FIG. 2B the oil displacement by a combustion drive is shown as being initiated at the end of the first stimulation injection period B_1. In a combustion drive air is conventionally injected at a constant rate and this results in a constant oil displacement rate. The oil displacement rate is substantially higher than the combined unstimulated producing rate during time period A. However, immediately after steam stimulation periods B_1, B_2, and B_3 the combined oil production rate is higher than the displacement rate but because of the production rate decline the producing rate approaches the displacement rate after a time period as represented by C_1, C_2, and C_3. The approach of the combined oil production rate to the displacement rate is utilized as a control for the initiation of steam injection to maintain the heated zone about the production wells. For example, when the combined producing rate of the two wells is approximately equal to the displacement rate by combustion the well having the lower production rate is taken off production and converted into a steam injection well and steam is injected into the formation in an amount and for a time that is sufficient to increase the combined production rate to a value well above the displacement rate. For example, at the end of time period B_1 the combined producing rate **21** of wells **6** and **8** is shown to be an amount indicated by the point **23**. The producing rate **21** is shown to decline during time period C_1 until it declines to an amount indicated by point **25** which is an amount about equal to the displacement rate by combustion **27**. Thereafter, steam injection is initiated into well **8** which is shown to have the lower production rate and continued during time period B_2 such that when the steam injection cycle is completed the combined production rate **21** is shown to be an amount indicated by point **29**.

I claim:

1. A method of producing hydrocarbons from a hydrocarbon-bearing formation, comprising:

a. providing a pattern of wells communicating with said formation, said pattern including an injection well, a first production well, and a second production well that is spaced laterally from said first production well a distance of no more than about **30** percent of the spacing between said injection and production wells;

b. injecting steam into said first production well and into said second production well to provide a heated zone about said first and second production wells;

c. initiating a forward in situ combustion drive from said injection well toward said first and said second production wells;

d. producing hydrocarbons from said formation via said first production well;

c. maintaining said heated zone about said production wells by injecting steam into said second production well while continuously producing hydrocarbons from said formation via said first production well;

f. alternately producing hydrocarbons from said formation via said second production well; and

g. maintaining said heated zone about said production wells by injecting steam into said first production well while continuously producing hydrocarbons from said formation via said second production well.

2. The method of claim **1** wherein concomitantly with step (b) steam is injected into said injection well thereby providing a quantity of flush hydrocarbons to be produced from said formation.

3. In the method of claim **1**:

producing hydrocarbons from said formation simultaneously via said first and said second production wells until the total production rate decreases to a rate about equal to the combustion drive oil displacement rate; and

selecting the production well having the lowest production rate and injecting steam into said production well having the lowest production rate to maintain said heated zone about said production wells and to increase said total production rate to a value substantially greater than said combustion drive oil displacement rate.

4. In the method of claim **1**:

producing hydrocarbons from said formation simultaneously via said first and said second production wells until the total production rate decreases to a rate about equal to the combustion drive oil displacement rate; and

selecting the production well nearest the combustion front and injecting steam into said production well nearest the combustion front to retard the movement of said combustion front toward said production well nearest said combustion front and to maintain said heated zone about said production wells.

5. A method of producing oil from an oil-bearing formation, comprising:

a. providing a pattern of wells that communicate with said formation, said pattern including an injection well, a first production well, and a second production well that is spaced laterally from said first production well a distance of no more than about **30** percent of the spacing between said injection and production wells;

b. producing oil via said first and said second production wells and determining the relative production rates of said first and said second production wells to determine said production well having a lower production rate and said production well having a higher production rate;

c. converting said production well having a lower production rate into a steam injection well and injecting steam via said steam injection well to increase the production rate of said well having a higher production rate while continuously producing oil from said formation via said well having a higher production rate;

d. converting said steam injection well into a production well and producing oil from said formation via said first and said second production wells; and

e. initiating a forward in situ combustion drive from said injection well toward said first and said second production wells.

6. The method of claim **5** further comprising:

f. determining the displacement rate of said in situ combustion process;

g. continuing the injection of steam in step (c) to provide a combined production rate that is greater than said displacement rate of said in situ combustion process;

h. continuing the producing of oil of step (d) until said combined production rate declines to an amount approximately equal to said displacement rate of said in situ combustion process;

i. thereafter repeating step (c) to provide a combined production rate that is greater than said displacement rate; and

j. producing oil from said formation via said first and said second production wells.

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