

Dec. 19, 1967

R. B. STELZER ET AL
RECOVERY OF HYDROCARBONS FROM UNDERGROUND
FORMATIONS BY IN SITU COMBUSTION

3,358,754

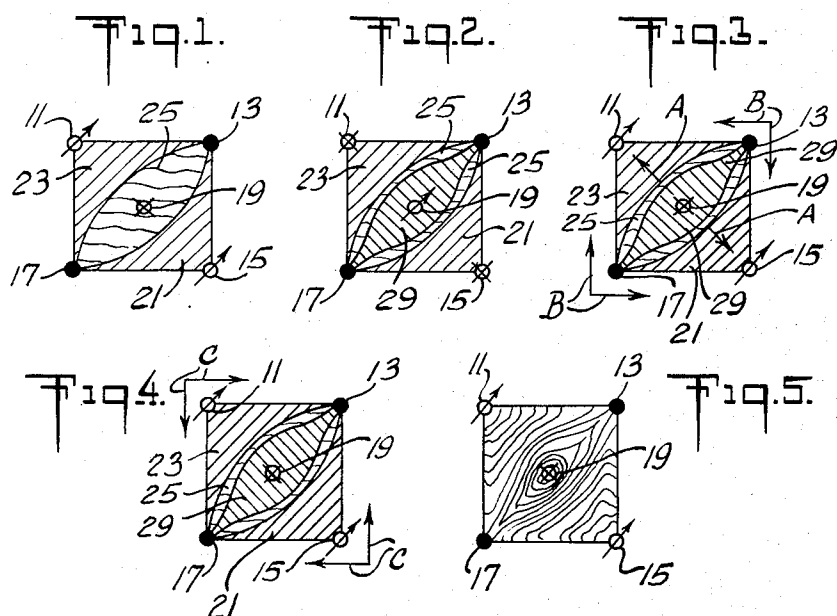
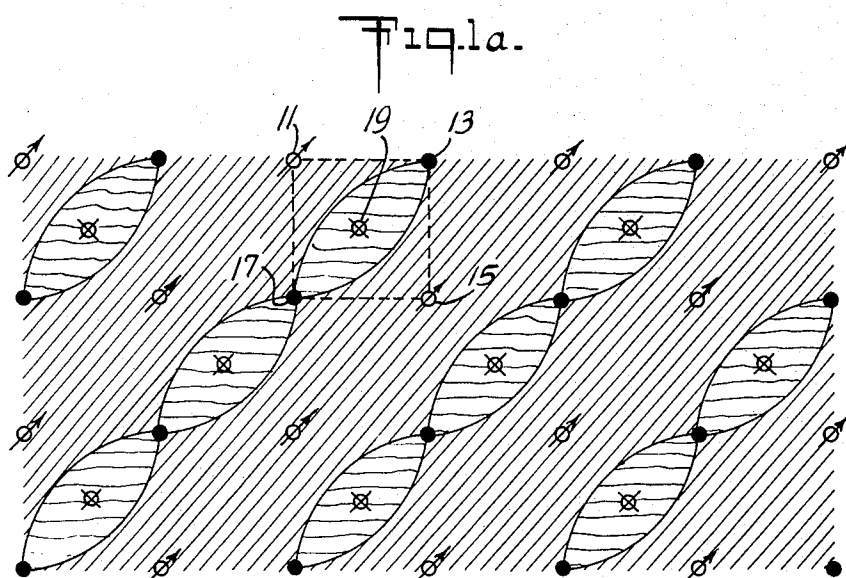
Filed Dec. 29, 1965

4 Sheets-Sheet 1

• Production Wells

⊕ Injection Wells

⊗ Shut-in Injection Wells



R. B. STELZER ETAL
RECOVERY OF HYDROCARBONS FROM UNDERGROUND
FORMATIONS BY IN SITU COMBUSTION

4 Sheets-Sheet 2

Fig. 2a.

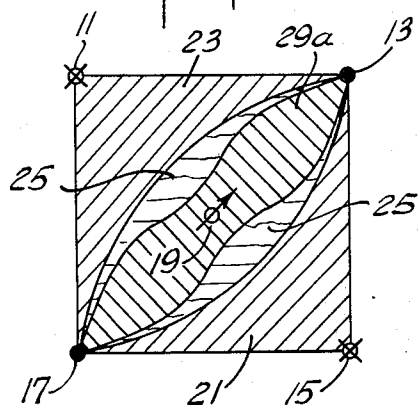
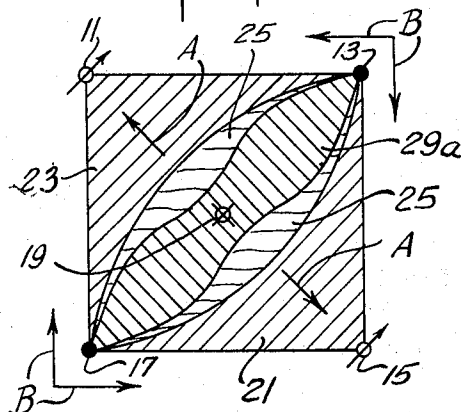
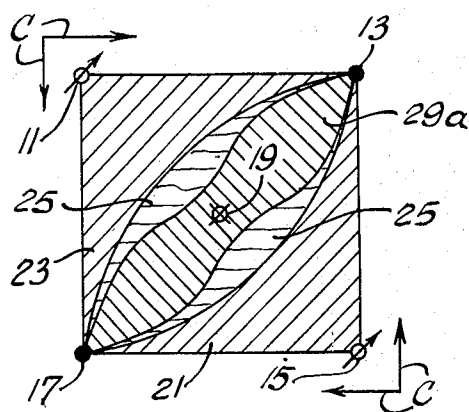


Fig. 3a.



T19.4a.



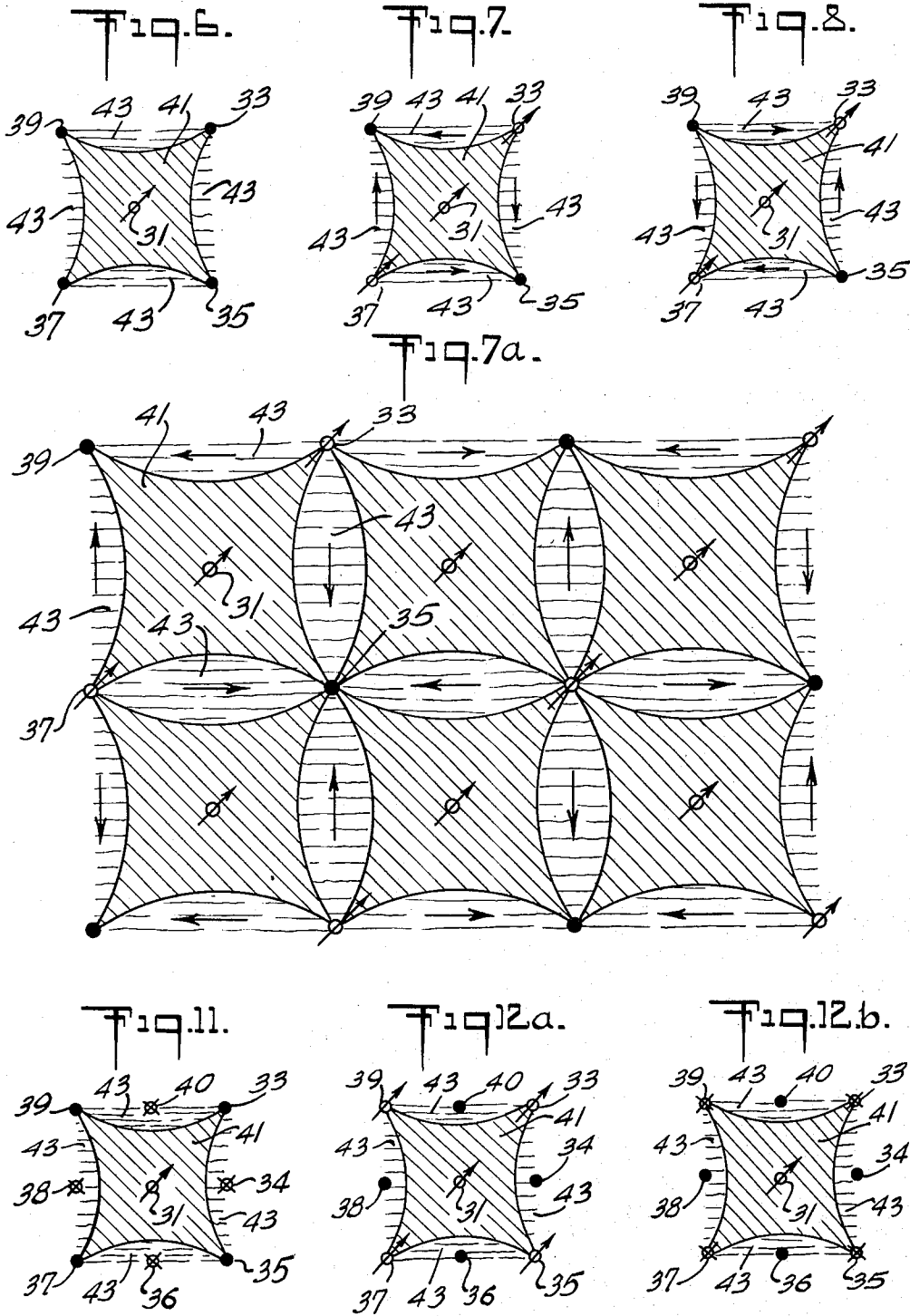
Dec. 19, 1967

R. B. STELZER ET AL
RECOVERY OF HYDROCARBONS FROM UNDERGROUND
FORMATIONS BY IN SITU COMBUSTION

3,358,754

Filed Dec. 29, 1965

4 Sheets-Sheet 3



Dec. 19, 1967

R. B. STELZER ET AL
RECOVERY OF HYDROCARBONS FROM UNDERGROUND
FORMATIONS BY IN SITU COMBUSTION

3,358,754

Filed Dec. 29, 1965

4 Sheets-Sheet 4

Fig. 9.

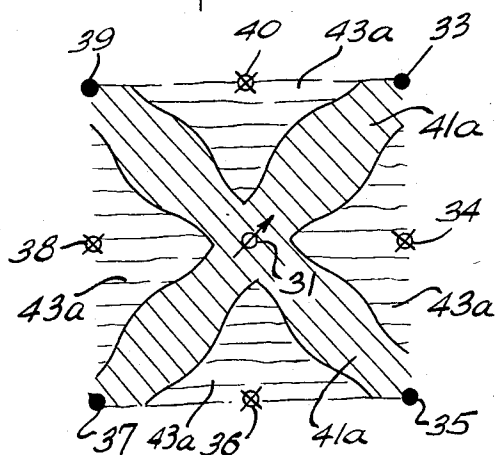


Fig. 10.

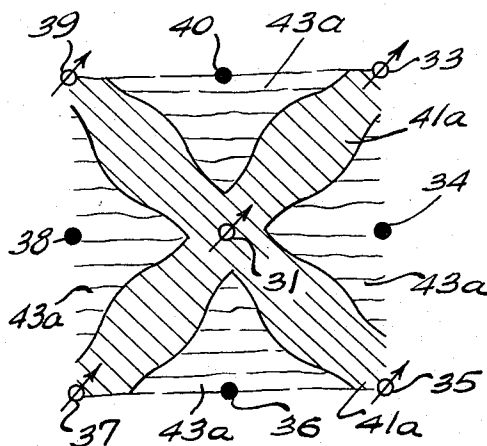
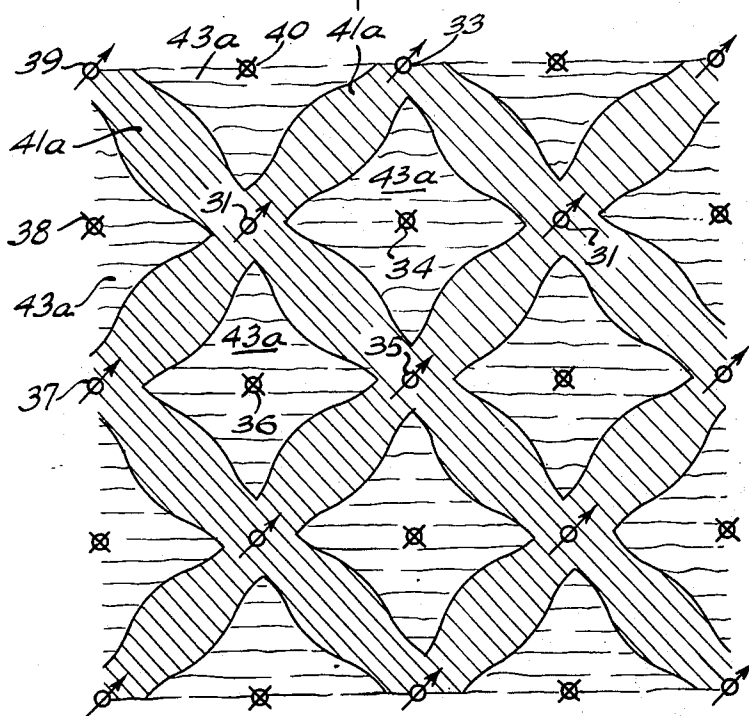


Fig. 9a.



1

3,358,754

RECOVERY OF HYDROCARBONS FROM UNDERGROUND FORMATIONS BY IN SITU COMBUSTION

Roland B. Stelzer and Robert E. Kunetka, Houston, and Joseph C. Allen, Bellaire, Tex., assignors to Texaco Inc., New York, N.Y., a corporation of Delaware
Filed Dec. 29, 1965, Ser. No. 517,247
14 Claims. (Cl. 166—2)

In the production of hydrocarbons from porous underground hydrocarbon bearing formations, it has been customary to drill one or more production wells to reach the hydrocarbon bearing formations and permit hydrocarbons, such as oil, to be produced through the 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 may still be present in the pores of the underground formations.

Many procedures have been employed for recovering the remaining hydrocarbons, one of them involving igniting and burning a portion of the hydrocarbons in place within the porous formation, whereby hot gases are generated to force hydrocarbons remaining in the formation toward a production well. While such in situ combustion has been quite successful in secondary recovery, it has been much less than 100% efficient because the combustion front tends to progress through the formation along locally channeled paths from the injection well to the production well, rather than sweeping the hydrocarbons as a bank from a broad area of the formation, thus bypassing substantial volumes of hydrocarbons in the formation.

It is an object of the present invention to provide a novel in situ combustion procedure, involving a well pattern arrangement, employing both concurrent and countercurrent in situ combustion in such a way as to exploit substantially the entire pattern arrangement in a depleted reservoir with established gas saturation, and to produce almost all of the hydrocarbons remaining in place in the formation. This is accomplished by changing the function of wells at strategic times in order to gain maximum control of the fire front.

In its broader aspects, our novel procedure for recovering hydrocarbons by in situ combustion from a gas pervious underground formation comprises establishing a well pattern wherein a plurality of wells are arranged in ring-like fashion around a central well, e.g., the well known 5-spot well pattern. The wells can be on 1/2-, 1-, 5-, or 10-acre spacings. In one aspect, initially the central well is shut in while air is pumped into a first pair of diametrically located wells to saturate a portion of the formation with air. Concurrently, hydrocarbons forced out of the formation by the air are produced from a second pair of the diametrically located wells, the diameters of the pairs of wells crossing each other.

When breakthrough of air occurs at the second pair of wells, the first pair of wells is shut in and air is injected into the central well with ignition of the formation hydrocarbons accomplished thereat, developing a flame front which moves outwardly from the central well to the second pair of wells, driving formation hydrocarbons thereto, as a result of a concurrent in situ combustion. Upon breakthrough of the high temperature flame front at the second pair of wells, the central well is shut in and air is injected into the first pair of wells while continuing to produce hydrocarbons at the second pair of wells. In this phase, because of the high temperature adjacent the boundary of the burned zone with the air saturated formation, there may be spontaneous initiation of a countercurrent in situ combustion between the production wells and the injection wells. Further, it may be necessary to initiate concurrent in situ combustion at the injection wells. Thus, by such a well pattern and change in functions of the wells, the formation is exploited by a combination of concurrent and countercurrent in situ combustion.

In a second aspect of the procedure, there is no air presaturation step, but only changes of well functions at appropriate times.

The above procedures or methods will be described in detail hereinafter with reference to the accompanying drawings wherein:

FIG. 1 depicts a 5-spot well pattern showing the first phase of the procedure, the right oblique section lines representing that part of the pattern area presaturated with air, and the horizontal wavy lines that part of the area unaffected by the air presaturation;

FIG. 1a is a showing of the concept of the 5-spot well pattern of FIG. 1, repeated for the exploitation of an entire reservoir;

FIG. 2 is a showing of the situation existent in a 5-spot well pattern at the time of breakthrough of the concurrent in situ combustion at the production wells, indicating the areas affected by the initial air presaturation, the in situ combustion, and the intervening unaffected area of the formation, the burn area being depicted by the left oblique section lines.

FIG. 2a is comparable to FIG. 2, showing the exploitation of a 5-spot well pattern wherein countercurrent in situ combustion has occurred, with the left oblique section lines indicating the burn area;

FIG. 3 shows the situation existent in FIG. 2 after the functions of the wells of the 5-spot well pattern have been changed to that shown in FIG. 1, for the start of the third phase of the procedure, the arrows indicating combustion processes;

FIG. 3a is comparable to FIG. 3 showing the result of countercurrent in situ combustion in a 5-spot well pattern;

FIG. 4 indicates the direction of travel of the concurrent in situ combustion initiated at the corner injection wells of a 5-spot well pattern as an addition to the combustion processes depicted in FIG. 3;

FIG. 4a is comparable to FIG. 4, showing a concurrent in situ combustion initiated at the corner injection wells of a 5-spot well pattern which has undergone a countercurrent in situ combustion burn;

FIG. 5 indicates the expected advance of a high temperature front with time, with concurrent in situ combustion during all the combustion phases, including ignition at the injection wells in the final phase;

FIG. 6 shows an inverted 5-spot well pattern, wherein breakthrough has occurred at the corner wells, the area swept by the concurrent in situ combustion being indicated by left oblique section lines and the unaffected area by horizontal wavy section lines;

FIG. 7 is a showing of the second phase of this aspect of the invention wherein diagonally based production wells are converted to function as injection wells, with initiation of a concurrent in situ combustion;

FIG. 7a is a showing of how the concept of FIG. 7 can be repeated for the exploitation of an entire reservoir;

FIG. 8 is a showing comparable to FIG. 7, indicating initiation of countercurrent in situ combustion;

FIG. 9 illustrates a 9-spot well pattern, showing the effect of countercurrent in situ combustion which has been initiated at the corner production wells with the side wells shut in, the burned out areas of the pattern being indicated by left oblique section lines and the unaffected areas of the pattern being indicated by horizontal wavy lines;

FIG. 9a is a showing of how this concept of the 9-spot

2

3

well pattern of FIG. 9 can be repeated for the exploitation of an entire reservoir;

FIG. 10, with the former production wells now operating as injection wells along with the central well, as in FIG. 9, and with only the side wells on production, indicates the second phase of the in situ combustion operation to clear the remaining unaffected pattern of the formation;

FIG. 11 corresponds to FIG. 9 and illustrates a 9-spot well pattern, showing the effect of concurrent in situ combustion which has been initiated at the central injection well with production at the corner wells, and the side wells shut in, the burned out areas of the pattern being indicated by left oblique section lines and the unaffected areas of the pattern being indicated by wavy lines;

FIG. 12a illustrates a second phase of the in situ combustion operation of FIG. 11 wherein the corner production wells are converted to function as injection wells along with the central injection well and production is initiated at the side wells; and

FIG. 12b illustrates an alternative second phase of the in situ combustion operation of FIG. 11, wherein the corner production wells are shut in and the side wells are put on production while injection continues through the central well.

The first phase of the method is illustrated in FIG. 1, showing the four corner wells 11, 13, 15 and 17 of a 5-spot well pattern and the central well 19. In this phase, the central well 19 is shut in and large volumes of air are pumped down into the two diagonally opposite injection wells 11 and 15, while the other diagonally located wells 13 and 17 are the production wells. This first phase is continued until breakthrough occurs at the production wells 13 and 17, at which time it is postulated that air saturation of the underground formation exists in the half cusp areas 21 and 23, while the elliptical area 25 between these half cusp areas is substantially unaffected by the injection of air.

At this time, the second phase of the method, as illustrated in FIG. 2, is begun. Then, the two injection wells 11 and 15 are shut in, the two production wells 13 and 17 remain open, and air injection is commenced into the central well 19 followed by the ignition of the formation at the central well 19 and in any of the ways which have become well known in this art and described in numerous patents, e.g., by a gas burner or an electrical heater. The burn or flame front of a concurrent in situ combustion develops and moves from the central well 19 outwardly to the two production wells 13 and 17, driving formation hydrocarbons from the double cusp like area within that of the ellipse 25 to recover almost all of the hydrocarbon content therein, as shown in the shaded area 29 of FIG. 2.

The second phase of the method is completed upon breakthrough of the high temperature flame front at the two production wells 13 and 17, at which time the condition exists as indicated in FIG. 2, showing the burned out area 29 with the high temperature flame front on its perimeter adjacent the contiguous previously established air saturated areas 21 and 23.

The third phase of the method is undertaken now, as illustrated in FIG. 3, wherein the alternate corner injection wells 11 and 15 are used for air injection again, production continuing at the corner wells 13 and 17, while the central well 19 is shut in again. It is postulated that the high temperature zone may invade the remainder of the pattern area and may involve the continuation of the combustion process outwardly along the boundary of the burned zone 29, as indicated by the arrows A, FIG. 3, by spontaneous countercurrent in situ combustion between the producing wells 13 and 17 and the injection wells 11 and 15, as indicated by the corner arrows B, FIG. 3.

Alternatively, during this third phase, a concurrent combustion can be initiated also at the injection wells 11 and 15, as indicated by the corner arrows C, FIG. 4,

4

while injecting air through the wells 11 and 15, and continuing the combustion processes indicated at A and B in FIG. 3, provided sufficient combustion supporting gas is available for these processes.

The advance of the high temperature flame front with time is shown in FIG. 5, the concurrent burn fronts being indicated by contour lines to show that the entire area of the pattern is produced ultimately.

At times, it may be desirable also that the first phase in which air saturation is established be conducted simultaneously with the combustion process of the second phase. Thus, the following functions are initiated simultaneously: air injection and ignition at the central well 19, air injection at the corner wells 11 and 15, and production from the corner wells 13 and 17.

It is a rare case when a producing oil field is exploited by a single 5-spot well pattern. More often a producing field includes a much larger pattern of numerous wells, as illustrated in FIG. 1a, showing how the first phase of the in situ combustion procedure, described in connection with FIGS. 1, 2, 3 and 4, can be repeated within a larger well pattern, so that substantially an entire reservoir can be exploited, the process steps being applied to a series of adjoining wells arranged in a series of polygonal figures within the pattern.

Further, the three phases of the procedure described in connection with FIGS. 1, 2, 3 and 4 also can be practiced for countercurrent in situ combustion for the exploitation of 5-spot well patterns. This practice is indicated in FIGS. 2a, 3a and 4a, illustrating conventional countercurrent burned out areas at 29a, the remaining numerations being the same as that in the corresponding FIGS. 2, 3 and 4, and can be applied to a larger well pattern in the same manner as the concurrent in situ combustion procedure.

Another modification of the invention to provide an efficient procedure for secondary recovery is illustrated in FIGS. 6 to 10 inclusive. In the first phase of this modification, air injection and ignition are effected at a central well 31 while production is taken from the four corner wells 33, 35, 37 and 39 of an inverted 5-spot well pattern. This phase, illustrated in FIG. 6, is continued until the high temperature flame front of the concurrent in situ combustion initiated at the center well 31 reaches the four production wells, at the corners of the pattern, at which time the concurrent burn will have exploited that area 41 of the pattern bounded by arcs defining the cusps generated by the corner production wells. At the termination of the first phase of this procedure, the areas 43 between each pair of production wells are left unswept.

Then, if it should be feasible and economically desirable to recover the oil from these unswept areas, the second phase of the procedure is initiated, viz, to insure that the injected air travel be confined to the oil saturated zone, e.g., by injecting pressurized fluid such as water and/or gas through the central well 31 to fill up and maintain a high pressure in the previously burned zone, so that excessive air will not by-pass through this zone. This phase of the procedure is maintained as long as needed during the third phase.

The third phase is initiated by changing the function of the corner production wells 33 and 37 to air injection wells as illustrated in FIG. 7, thereby to continue the concurrent in situ combustion of the formation hydrocarbons toward the other pair of corner production wells 35, 39 as indicated by the arrows in FIG. 7, or the countercurrent in situ combustion as indicated by the arrows in FIG. 8 or a combination of the two, depending on conditions of oxygen concentration, oil mobility and temperature, so that the unswept areas 43 are cleared of formation hydrocarbons. Continuance of gas injection (or water injection) at the central well 31 will contribute a pressure gradient to produce a flame front velocity perpendicular to the major axis of the unswept areas.

The in situ combustion procedure described in con-

5

nection with FIGS. 6, 7 and 8 can be applied advantageously to a field of substantial extent, wherein many wells have been drilled, by repeating the pattern within a larger well pattern as illustrated in FIG. 7a of the drawings.

FIGS. 9 and 10 illustrate the application of counter-current combustion to a 9-spot well pattern, starting with the first phase of the operation as illustrated in FIG. 6, the corner production and central injection wells having the same numeration respectively, while the side wells 34, 36, 38 and 40 are shut-in. At the end of the first phase, the resultant unswept areas are indicated as 43a and the burned out areas 41a in FIG. 9 of the drawings.

The second phase of the operations illustrated in FIG. 10, wherein not only is the central well continued as an injection well, but the corner wells are converted from production wells to injection wells, and countercurrent in situ combustion and production are initiated at the side wells 34, 36, 38 and 40. Provided temperatures at the edges of the unswept zones remain sufficiently high for combustion, concurrent in situ combustion may also occur.

As in the cases of FIGS. 1 and 1a, and FIGS. 7 and 7a, the countercurrent in situ combustion operation as illustrated in FIG. 9 can be repeated within a larger well pattern as illustrated in FIG. 9a.

FIG. 11 illustrates the end of the first phase of a concurrent in situ combustion operation initiated at the corner production wells 33, 35, 37 and 39 of a 9-spot well pattern with injection at the central well 31, and with the side wells 34, 36, 38 and 40 shut in.

FIGS. 12a and 12b illustrate alternate beginnings of the second phase of the in situ combustion operation illustrated in FIG. 11. In the former figure, the corner production wells are converted to injection wells to function along with the central injection well and the side wells are open to production following the initiation of concurrent in situ combustion thereat, while in the latter figure, the corner production wells are shut in while injection is maintained at the central well, and the side wells are opened to production. If temperatures at the edges of the unswept zone have fallen below ignition temperature for concurrent combustion, with respect to the side production wells, countercurrent combustion may be initiated at the side production wells.

As in the case of FIGS. 6 to 10, pressurized fluid may be injected through the central well 31 to maintain a high pressure in the previously burned zone.

Thus, there has been shown and described an advantageous procedure for efficiently and economically sweeping hydrocarbons from substantially the entire area of a depleted underground hydrocarbon bearing reservoir, wherein a substantial quantity of hydrocarbons is left in place within the formation after the primary production has ceased. While the procedure has been illustrated by application to a 5-spot well pattern, it is evident that the principles are applicable also to other types of well patterns. While the term "air" has been employed, this is intended to include any combustion supporting gas mixture such as oxygen or oxygen enriched air.

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.

We claim:

1. A process for recovering hydrocarbons by in situ combustion from a gas pervious underground hydrocarbon bearing formation by exploitation through a well pattern of a central well and a plurality of wells surrounding said central well in ring-like fashion comprising

- (a) pumping air down into a first pair of diametrically located wells of said pattern, while
- (b) concurrently producing hydrocarbons from a second pair of diametrically located wells, the diameters of the pairs of wells crossing each other,

6

(c) shutting in said first pair of wells upon breakthrough of air at said second pair of wells,

(d) injecting air into said central well and igniting the hydrocarbon bearing formation thereat, thereby developing a concurrent in situ combustion front with respect to said second pair of wells, and

(e) upon breakthrough of said in situ combustion front at said second pair of wells, again injecting air into said first pair of wells while continuing producing hydrocarbons at said second pair of wells.

2. A process in accordance with claim 1 wherein said well pattern is 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.

3. A process in accordance with claim 1 wherein said pattern is a 5-spot well pattern.

4. A process in accordance with claim 1 wherein during step (a), said central well is shut in.

5. A process in accordance with claim 1 wherein steps (a) and (b) are conducted simultaneously.

6. A process in accordance with claim 1 wherein during step (e), said central well is shut in, and countercurrent in situ combustion is initiated between said second pair of production wells and said first pair of wells.

7. A process in accordance with claim 6, also comprising initiating concurrent in situ combustion at said first pair of injection wells with respect to said second pair of wells.

8. A process for recovering hydrocarbons by in situ combustion from a gas previous 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 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 hydrocarbons from said diametrically positioned wells until said high temperature combustion front breaks through thereat,

(c) 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 (d) is restricted to the hydrocarbon bearing formation outside of said zone,

(d) ceasing production at and thereafter commencing the injection of air into a first pair of said diametrically positioned wells and continuing said in situ combustion of formation hydrocarbons while continuing producing hydrocarbons from a second pair of diametrically positioned wells, the diameters of the pairs of wells intersecting angularly.

9. A process in accordance with claim 8 wherein said well pattern is a 5-spot well pattern.

10. A process in accordance with claim 8 wherein said well pattern is 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.

11. A process for recovering hydrocarbons by in situ combustion from a gas pervious underground hydrocarbon bearing formation by exploitation through a well pattern of a central well surrounded by a ring of wells comprising

(a) injecting air into said central well while concurrently initiating in situ combustion at pairs of diametrically located wells, the diameters of said wells intersecting angularly, and thereafter

(b) producing hydrocarbons from said pairs of diametrically located wells, until hydrocarbon production falls off indicating approaching completion of said in situ combustion along said diameters, and

(c) ceasing producing hydrocarbons from said pairs of diametrically located wells and injecting air thereat while maintaining air injection at said central

well and producing hydrocarbons from pairs of diametrically positioned wells located between said diameters of said pairs of said diametrically located wells while said in situ combustion proceeds to completion.

12. A process in accordance with claim 11 wherein said well pattern is a 9-spot well pattern.

13. A process in accordance with claim 11 wherein said well pattern is 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.

14. A process in accordance with claim 11 wherein step (a) is modified by initiating in situ combustion at said central well and withholding initiation of in situ combustion at said pairs of diametrically located wells.

References Cited

UNITED STATES PATENTS

2,347,778	5/1944	Heath	166—2
2,885,002	5/1959	Jenks	166—9
2,888,987	6/1959	Parker	166—11 X
3,113,617	12/1963	Oakes	166—9
3,120,870	2/1964	Santourian	166—9
3,143,169	8/1964	Foulks	166—9
3,152,638	10/1964	Geffen et al.	166—11 X
3,154,143	10/1964	Parrish	166—11
3,167,117	1/1965	Santourian	166—11
3,199,587	8/1965	Santourian	166—9
3,246,693	4/1966	Crider	166—11 X

15 STEPHEN J. NOVOSAD, *Primary Examiner*.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,358,754

December 19, 1967

Roland B. Stelzer et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 6, for "seocnd" read -- second --;
column 4, line 73, for "product" read -- produce --;
column 6, line 21, for "(b)" read -- (d) --; line 31, for
"previous" read -- pervious --.

Signed and sealed this 14th day of January 1969.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

EDWARD J. BRENNER

Commissioner of Patents