

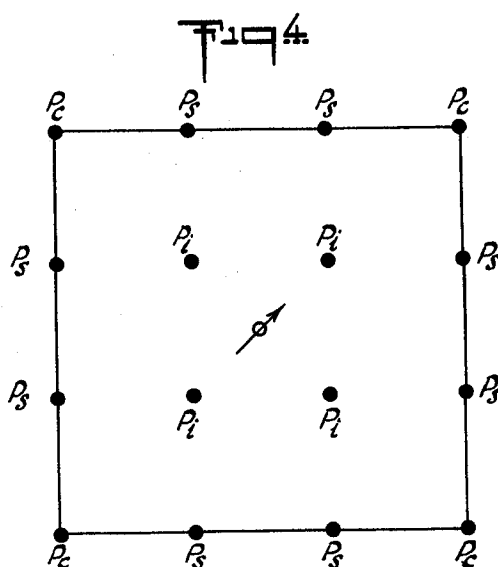
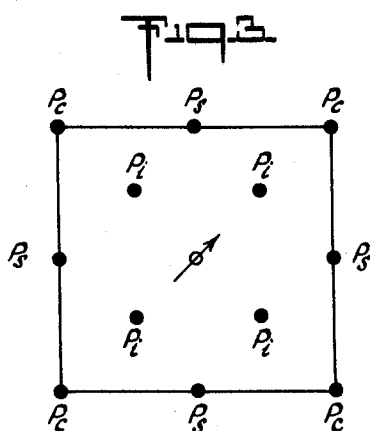
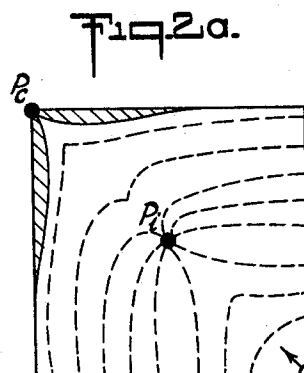
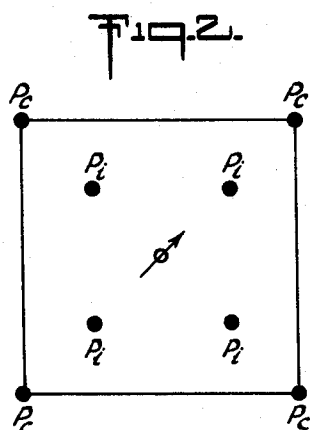
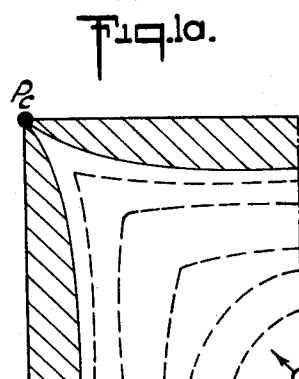
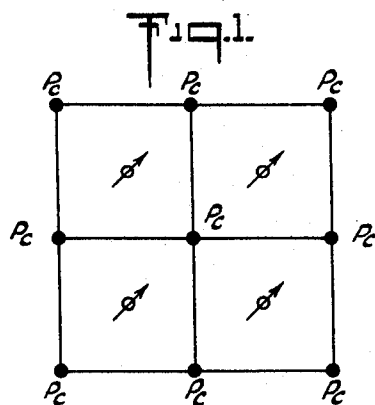
July 23, 1968

A. F. ALTAMIRA ET AL
INTERFACE ADVANCE CONTROL IN PATTERN FLOODS BY
USE OF CONTROL WELLS

3,393,735

Filed Dec. 23, 1965

3 Sheets-Sheet 1



July 23, 1968

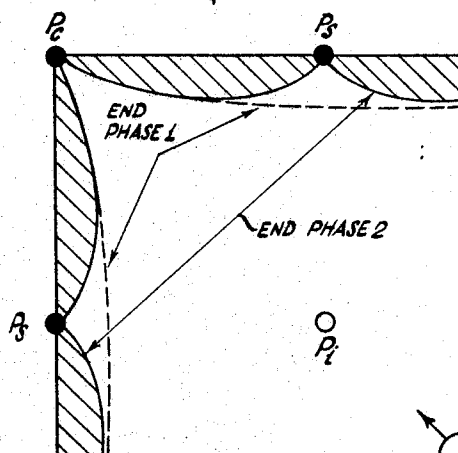
8 A. F. ALTAMIRA ET AL 3,
INTERFACE ADVANCE CONTROL IN PATTERN FLOODS BY
USE OF CONTROL WELLS

3,393,735

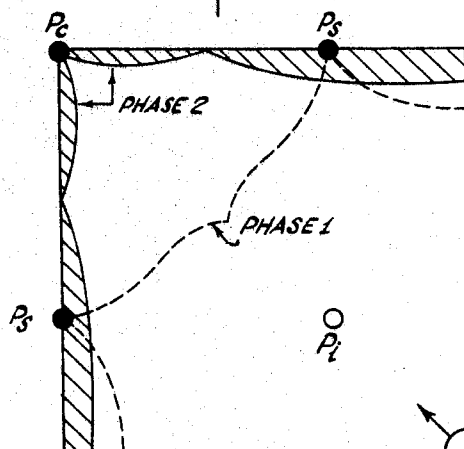
Filed Dec. 23, 1965

3 Sheets-Sheet 2

F194a.



F1Q4b.



July 23, 1968

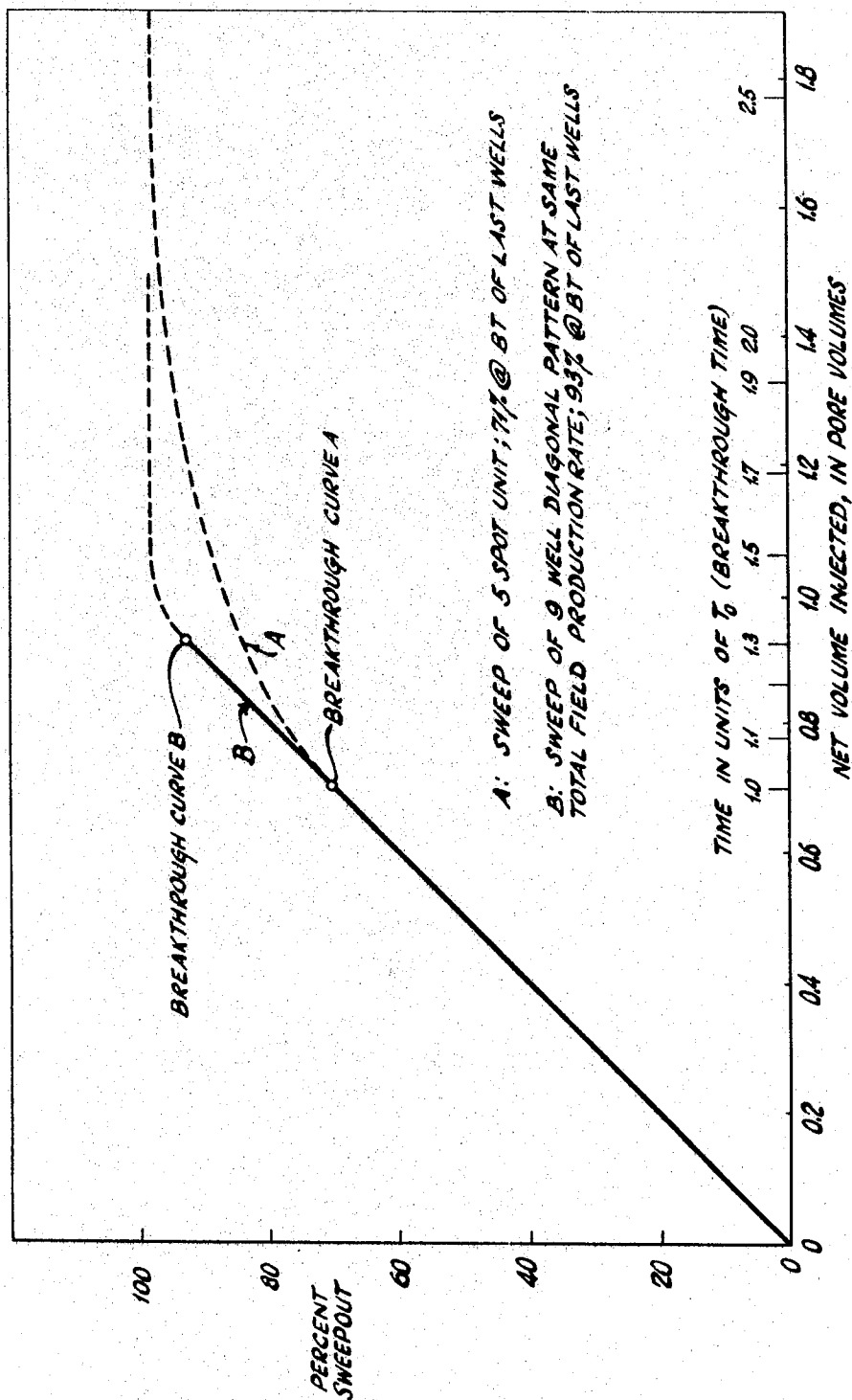
A. F. ALTAMIRA ET AL
INTERFACE ADVANCE CONTROL IN PATTERN FLOODS BY
USE OF CONTROL WELLS

3,393,735

Filed Dec. 28, 1965

3 Sheets-Sheet 3

Fig. 5.



1

3,393,735

**INTERFACE ADVANCE CONTROL IN PATTERN
FLOODS BY USE OF CONTROL WELLS****Anthony F. Altamira and Donald L. Hoyt, Houston, Tex.,
assignors to Texaco Inc., New York, N.Y., a corpora-
tion of Delaware****Filed Dec. 28, 1965, Ser. No. 517,052****14 Claims. (Cl. 166-9)****ABSTRACT OF THE DISCLOSURE**

A method of producing and recovering hydrocarbons from a subterranean hydrocarbon-bearing formation wherein control wells, interposed between injection and production wells, are used in combination with production wells to regulate the advance of the formation and injected fluids in a selected pattern unit whereby the areal sweep efficiency across the pattern is increased.

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

In exploiting underground hydrocarbon-bearing formations through a plurality of wells, it has been the general practice that when a production well yields an excessive amount of an extraneous fluid other than the hydrocarbons, e.g., water or gas, that production well is shut-in and the production of hydrocarbons is started and carried out at other production wells in the field. It is known that in such instances, a substantial amount of hydrocarbons is left behind in the hydrocarbon-bearing formation since such is not considered primarily recoverable economically.

Secondary recovery programs are now an essential part of the over-all planning for virtually every oil and gas-condensate reservoir in underground hydrocarbon-bearing formations. In general, this involves injecting a fluid into the reservoir zone to drive the oil or gas toward producing wells by the process frequently referred to as "flooding." Usually, this flooding is accomplished by drilling wells in a geometric pattern, the most common pattern being 5-spot.

When fluid from the injection well reaches the producing wells in a 5-spot pattern, the areal sweep efficiency is about 71%. By continuing production well past breakthrough, it is possible to produce much of the remaining unswept portion. It would be a great economic benefit to be able to achieve a sweep efficiency of 100% of the hydrocarbon-bearing formation. It would be an even greater benefit to be able to achieve it at breakthrough, so that it would not be necessary to produce large quantities of injected fluid.

Accordingly, it is an object of the present invention to provide an improved method for the production and recovery of hydrocarbons, particularly liquid petroleum, from underground hydrocarbon-bearing formations.

Another object of this invention is to provide a method whereby the areal sweep efficiency in pattern flooding is improved.

These and other objects, advantages and features of this invention will become apparent from a consideration of the specification with reference to the figures of the accompanying drawings wherein:

FIG. 1 discloses four units of an inverted 5-spot pattern;

FIG. 1a is illustrative of the interface advance in the form of a cusp toward a corner producing well in one quadrant of such a 5-spot pattern undergoing secondary recovery;

2

FIG. 2 discloses one unit of a 9-well diagonal pattern;

FIG. 2a corresponds to FIG. 1a, illustrating the effect of a control well as it retards the advance of the interface of the cusp toward a corner producing well in one quadrant of such a 9-well pattern undergoing secondary recovery;

FIG. 3 discloses one unit of a 9-spot pattern, modified by the addition of control wells between the injection well and the corner producing wells for a secondary recovery program;

FIG. 4 discloses one unit of a 17-spot pattern;

FIGS. 4a and 4b illustrate the movement of the interface during the phases of the production program in one quadrant of such a 17-spot pattern undergoing secondary recovery; and

FIG. 5 is a graph showing the more effective sweep-out when the method of this invention is applied to a 9-well diagonal pattern, as compared with the inverted 5-spot pattern.

The objects of our invention are achieved by the use of control wells in combination with production wells to retard the formation of the usual cusp interface by the advance of formation and injected fluids to the production wells of a selected pattern unit.

By our invention, an increased amount of hydrocarbons is produced and recovered from an underground hydrocarbon-bearing formation by employing at least three wells, penetrating such a formation, which wells are in-line, to produce hydrocarbons from the formation via two of these wells including the middle well, as disclosed in the co-assigned U.S. Patent No. 3,109,487, issued to Donald L. Hoyt, on Nov. 5, 1963, the disclosure of which is incorporated herein by this reference thereto. Further, as disclosed in the aforesaid patent, the hydrocarbons produced and recovered from the formation via the middle well are handled for further treatment, and extraneous fluid, such as water or gas, produced along with the hydrocarbons via the middle well is recovered and returned to the hydrocarbon-bearing formation via the third of the aforementioned three wells.

Referring now to figures of the drawings, which schematically illustrate the practice and advantages of our invention, there are illustrated several well patterns and areal sweep-out examples which are obtainable and have been observed both in secondary recovery operations and in potentiometric model studies which simulate secondary recovery operations. The model studies indicate a sweep-out obtained in an ideal reservoir although the recovery from an actual sweep-out of a particular field may be greater or less depending on field parameters. The results to be described were based on the following set of experimental conditions and assumptions:

(1) The ratio of total fluid production rates between wells is constant for any given phase or step in the production plan for all units in a pattern (a pattern unit is the basic group of an injection well with surrounding production wells, the repetition of which makes up the over-all pattern of the production field);

(2) All the units in any pattern produce at the same rate (this requires that wells at the edge of the field produce at $\frac{1}{4}$ or $\frac{1}{2}$ of the rate of corresponding interior wells, depending on whether they are corner or side wells, respectively, in a pattern unit);

(3) The total field injection and production must balance for each pattern unit, as well as for the whole pattern;

(4) The mobility ratio of the displacing to the displaced fluid is 1.0;

(5) Gravitational effects are not considered.

Referring to FIG. 1, there is disclosed four units of an inverted 5-spot pattern wherein the corner wells of

3

each pattern unit are producing wells, while the inner central well is used for injection. Throughout the drawings the same symbols will be maintained as follows: P_c , P_s and P_i represent respectively wells at the corners, along the sides, and the interior control wells of the pattern, and, a solid circle indicates a production well, a crossed circle indicates a shut-in well, and an arrowed circle indicates an injection well.

FIG. 1a illustrates the growth of the cusp in one quadrant of an inverted 5-spot pattern unit, wherein the secondary flooding fluid is injected into the central well and production is maintained at the corner wells until breakthrough. Such a procedure will produce a sweep-out of approximately 71%.

Referring to FIG. 2, there is disclosed a 9-well diagonal pattern, essentially the 5-spot pattern with control wells positioned on the diagonals between the central injection well and the corner production wells. The control wells should be spaced at least one half the distance between the injection well and each corner production well, with the best results obtained when such control wells are positioned between three-quarters and seven-eighths the distance from the injection well toward the corner production wells. With such a pattern, the invention disclosed in the coassigned cited patent to Hoyt can be employed with success to increase the sweep-out area over that mentioned for the basic 5-spot pattern.

FIG. 2a illustrates the effect of the control well as it retards the advance of the cusp. As disclosed in the above-mentioned patent to Hoyt, the advance of the cusp has been "pinned" thereby delaying the advance and accentuation of the pointed cusp interface, as illustrated in FIG. 1a, to produce an oblate cusp interface, resulting in a greater sweep-out. The procedure employed in achieving such a sweep requires providing the flooding fluid to the central injection well and maintaining production at both the control or interior wells and the corner production wells until breakthrough at the corner production wells. In an alternative method, initially, production is maintained continuously only at the interior control wells until breakthrough thereat, and then production is initiated and maintained at the corner production wells until breakthrough thereat. The sweep-out in each instance is substantially the same, with differences in the amounts of injected fluid produced at the interior control wells.

The table listed below indicates several combinations of control well positions and rate distributions which will produce a 93 to 96% sweep-out, with different amounts of injected fluid produced by each combination.

TABLE I.—9-WELL DIAGONAL PATTERN

Rate, qp:qc	Control-Well Distance	Percent Swept at Breakthrough in Corner Well	Amount of Injected Fluid Produced in Pore V
4:1	$\frac{3}{2}$	83.0	0.51
1:1	$\frac{3}{2}$	91.0	1.82
1:2	$\frac{3}{2}$	93.0	3.04
4:1	$\frac{3}{4}$	83.0	0.20
2:1	$\frac{3}{4}$	87.9	0.39
1:1	$\frac{3}{4}$	93.0	0.95
1:2 Phase I	$\frac{3}{4}$		
1:1 Phase II		93.5	0.63
2:1 Phase I	$\frac{3}{4}$	94.5	0.68
1:1 Phase II			
4:1	$\frac{7}{8}$	80.4	0.08
2:1	$\frac{7}{8}$	86.2	0.16
1:1	$\frac{7}{8}$	89.2	0.30
1:2	$\frac{7}{8}$	95.7	0.82
1:2 Phase I	$\frac{7}{8}$	92.9	0.39
1:1 Phase II			

Rate—qp:qc=q production/q control.
Phase I—Until control well breakthrough.
Phase II—Until production well breakthrough.

FIG. 3 discloses the basic 9-spot pattern modified by the addition of the interior control wells, which can be positioned on the diagonals of the pattern for best advantage as indicated by the data of Table I. It can be visualized also as a four unit 5-spot pattern, wherein the injection wells of the inverted 5-spot pattern units have been

4

converted to production wells, and the innermost production well of the four unit 5-spot pattern has been converted into an injection well. With such a conversion, the positions of the control wells have been predetermined and may not be situated for best effect.

The first phase of the production method requires the providing of injection fluid to the central well and production initiated and maintained at the four control wells and also at the side wells until breakthrough is achieved at the side wells, the rates of production being adjusted as desired for simultaneous breakthrough at all production wells. At that time, the four side wells are shut in, production is initiated and maintained at the corner production wells while maintaining production at the interior control wells until breakthrough at the corner wells. By the two phases of this method when applied to the 9-spot pattern as modified by the addition of control wells, a sweep-out of approximately 90% follows.

FIG. 4 discloses a 17-spot pattern which is formed by drilling a single injection well in a center of a 4 x 4 well square. It can be seen readily that the 17-spot pattern has an advantage of requiring the drilling of one injection well per 9 production wells. In this 17-spot pattern, there are four corner production wells, 2 producing side wells on each side of the 4 x 4 well square, and four interior control wells located on the diagonals of the pattern and positioned between the central injection well and the corner production wells. In this instance, it may not be possible that the selective positioning of the control wells, as mentioned for the patterns disclosed in FIGS. 2 and 3, be met, since it would be used in fields which have been developed and would not require any preplanning as in the case of the 9-well diagonal pattern.

Referring to FIGS. 4a and 4b, there are illustrated two steps or phases of the production method as applied to the 17-spot pattern. In the first phase, production is maintained at the four interior control wells and each of the corner wells until breakthrough is achieved at the corner wells. Injection being maintained at the central injection well. The end of the first phase is defined by the dotted lines of FIG. 4a. In the second phase, the corner production wells and the interior control wells are shut in and production is initiated and maintained at the side wells until breakthrough thereat. The resultant unswept area is defined by cross hatching within the solid lines in FIG. 4a, with a sweep-out of 85%, a smaller improvement than that of preceding patterns because of the closer position of the control well to the injection well.

The method disclosed in FIG. 4a, is essentially that shown in FIG. 2a, with the addition of production side wells used until breakthrough thereat.

FIG. 4b illustrates a different application of our method in which the first phase includes production not only from the interior control wells but also from the side wells until breakthrough thereat. The dotted outline in FIG. 4b defines the end of this phase. The second phase comprises production from the corner wells only until breakthrough, leaving an unswept area defined by the cross hatching within the solid lines in FIG. 4b, to give a sweep-out of approximately 90%. Not only is the sweep-out greater but the volume of injected fluid is reduced to $\frac{1}{6}$ of that produced in the initial procedure.

A comparison between FIGS. 2a and 4a will reveal the difference in sweep-out areas and emphasize the advantage of positioning the control wells closer to the respective corner production wells.

The increase in sweep-out of the hydrocarbon area results from hindering the development of a cusp in interface as it grows towards a producing well. If the other portions of the interface could be made to keep up or if the cusp could be held back, it might be possible to achieve 100% areal sweep. The positioning of a control well between a production well and the injection well, and kept on production after the injection fluid reaches it, effectively pins down the cusp at this point while the

rest of the interface can continue to advance. This procedure greatly increases the area swept by the injected fluid before it reaches the most distant production well. However, considerable quantities of injection fluid produced from the control wells may be required to be handled.

A summary of the actual experimental data is presented in Table II, showing the increase in sweep-out from the 71% obtainable from the conventional inverted 5-spot pattern to over 90% by using other patterns with the steps described above.

In addition to the type of well pattern, the table includes:

(a) Position of control well (when used), given as the fraction of the distance from injection well to corner production well in a pattern unit;

(b) Rate distribution, given as the ratio of total fluid production of each production well to that of each control well in the pattern unit ($Q_p:Q_c$);

(c) Percentage of sweepout at breakthrough into the last production well;

(d) Volume of injected fluid produced, in terms of pore volume of any field using the indicated pattern;

(e) A brief description of the production procedure for each indicated pattern.

5 is an optimum and may fall off much more sharply. Curve B, however, representing experiment A-5 (as example), indicates the advantage of the 9 well diagonal pattern, if injection and production levels can be maintained. The higher sweep-out is more likely to be achieved (since it is obtained prior to breakthrough of the last production wells) and it will be obtained in a shorter time.

The advantages of the methods disclosed above are evident. Fewer injection wells are required, more reservoir fluid is recovered prior to breakthrough of injection fluid, and so more ultimate recovery is obtained, as compared with other methods generally employed in secondary recovery operation. Any pattern and/or rate distribution which retards the development, or the advance, of a cusp towards the producing wells will increase the sweepout of a field.

Although emphasis has been placed in this disclosure on the practice of this invention as directed to a secondary recovery operation, particularly employing water or other similar aqueous fluid as the injection fluid or displacement fluid, as indicated hereinabove, the advantages obtainable in the practice of this invention are also realized in primary hydrocarbon production operations wherein the hydrocarbon-bearing formation is under the influence of

TABLE II

Pattern Type and Experiment No.	Position of Control Well	Rate Distribution ($Q_p:Q_c$)	Areal Sweep Efficiency	Vol. Inj. Fluid Produced, in Pore Vol.	Procedure
5-Spot.....	None	Uniform.....	71	0	All wells producing at Q_p to BT.
9-Well Diagonal:					
A-1.....	$\frac{1}{2}$	4:1.....	83	0.51	Produce all wells to BT of corners.
A-2.....	$\frac{1}{2}$	1:1.....	91	1.82	Same as A-1.
A-3.....	$\frac{1}{2}$	1:2.....	93	3.04	Same.
A-4.....	$\frac{3}{4}$	4:1.....	83	0.20	Do.
A-5.....	$\frac{3}{4}$	1:1.....	93	0.95	Do.
17-Spot:					
B-1.....	$\frac{1}{3}$	4:1.....	84	0.63	{B-1-A. Produce K & C to BT of K. B-1-B. SI K & C; produce S to BT.
B-2.....	$\frac{1}{3}$	1:1.....	85	2.86	{B-2-A. Same as B-1-A. B-2-B. Same as B-1-B.
B-3.....	$\frac{1}{3}$	{2:1 (A)..... 4:1 (B).....}	91	0.54	{B-3-A. Produce S & C to BT of S. B-3-B. SI S; produce K & C to BT of K.
B-4.....	$\frac{1}{3}$	1:1.....	90	1.79	{B-4-A. Same as B-3-A. B-4-B. Same as B-3-B.
B-5.....	$\frac{1}{3}$	{None (A)..... 4:1 (B).....}	88	0.27	{B-5-A. Produce S only, to BT. B-5-B. Same as B-3-B.

Nomenclature.—BT=Breakthrough; SI=Shut In; C=Control Wells; S=Side Wells; K=Corner Wells.

In evaluating the performance of a flood pattern, or in comparing performance of different patterns, there are three main considerations:

- Percentage of sweep
- Volume of injection fluid handled
- Time to achieve the sweep

For a given total field production rate, it will not be possible generally to obtain an increase in sweep-out without at least a proportionate increase of time, which is to be expected. However, if the extra time involved is disproportionately long, the gain in sweep-out may not be economically worthwhile.

Similarly, it is possible that the amount of injection fluid which must be produced and processed in order to achieve such additional sweep can make a particular plan unattractive. On the other hand, the much lower ratio of injection wells to production wells in the plan may lower the drilling costs to such an extent as to more than make up for the handling of injected fluid. These factors must all be considered and calculated for each individual situation as it occurs.

It is recognized that production is normally contained past breakthrough in 5-spot operations and in fact, the cumulative sweep may even reach 95% or more as shown by curve A of FIG. 5.

However, production can be continued beyond last breakthrough in the various other patterns also, so that the comparison of sweepout at breakthrough of the last production well should be valid. Furthermore, the increase in percentage of sweep shown by curve A of FIG.

a water drive or gas drive, or both a water and a gas drive, and also in the instance of a secondary recovery operation wherein a gas, such as natural gas, is employed as the injection fluid.

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 method of producing hydrocarbons from an underground hydrocarbon-bearing formation involving an injection well surrounded by production wells located on the diagonals of a quadrilateral with at least two of said production wells being substantially in-line with said injection well and spaced thereby from a similar pair of said production wells positioned along the same diagonal, which comprises introducing injection fluid into said formation via said injection well, producing hydrocarbons from said formation via the production wells on said diagonals closer to said injection well, maintaining the production of hydrocarbons from the aforesaid production wells closer to said injection well when said injection fluid begins to appear and is produced along with hydrocarbons via the closer production wells, producing hydrocarbons from said formation via the production wells on said diagonals farther removed from said injection well, and maintaining the production of hydrocarbons from said production wells farther removed from said injection well until breakthrough of said injection fluid is observed thereat, meanwhile producing hydrocarbons and

said injection fluid from the aforesaid production wells closer to said injection well.

2. In the method of producing hydrocarbons as defined in claim 1, the production of hydrocarbons from said production wells located on the diagonals of a quadrilateral being concurrent until breakthrough of injection fluid at said farther removed production wells.

3. In the method of producing hydrocarbons as defined in claim 1, the production of hydrocarbons from said production wells farther removed being initiated after breakthrough of said injection fluid at said production wells closer to said injection well.

4. In the method of producing hydrocarbons as defined in claim 1 wherein production wells are positioned along the sides of said quadrilateral having production wells located along the diagonals thereof, producing hydrocarbons from said formation from said production wells positioned along the sides of said quadrilateral.

5. In the production of hydrocarbons as defined in claim 4, producing hydrocarbons from the quadrilateral side production wells concurrently with producing hydrocarbons from said production wells located along the quadrilateral diagonals until breakthrough of said injection fluid at the farther removed diagonal wells.

6. In the production of hydrocarbons as defined in claim 4, initiating and maintaining the production of hydrocarbons from the quadrilateral side production wells after breakthrough of said injection fluid at the closer diagonal production wells, while maintaining production of hydrocarbons and injection fluid thereat.

7. In the production of hydrocarbons as defined in claim 6, initiating the production of hydrocarbons at the farther removed diagonal production wells after breakthrough of said injection fluid at said quadrilateral side production wells and ceasing producing hydrocarbons thereat and at said closer diagonal production wells and maintaining production of hydrocarbons at said farther removed diagonal production wells until breakthrough of injection fluid thereat.

8. In the production of hydrocarbons as defined in claim 7, the additional steps following breakthrough of injection fluid at said farther removed diagonal production wells of ceasing the production of hydrocarbons thereat and again producing from said quadrilateral side production wells until breakthrough of injection fluid again.

9. In the production of hydrocarbons as defined in claim 4, the production of hydrocarbons from the quadrilateral side production wells and the farther removed diagonal production wells being initiated consecutively following breakthrough of said injection fluid at said production wells closer to said injection well and said quadrilateral side wells respectively.

10. In the production of hydrocarbons as defined in claim 2 wherein production wells are positioned along the sides of said quadrilateral having production wells located along the diagonals thereof, initiating and maintaining the production of hydrocarbons from said formation from the production wells positioned along the sides of said quadrilateral until breakthrough of said injection fluid at the quadrilateral side wells, meanwhile ceasing the production of hydrocarbons from the diagonal production wells.

11. In the production of hydrocarbons as defined in claim 9, each side of said quadrilateral having a single well positioned thereon.

12. In the production of hydrocarbons as defined in claim 9, each quadrilateral side having at least two wells located thereon.

13. In the production of hydrocarbons as defined in claim 4, producing hydrocarbons from said formation via the closer diagonal production wells and the quadrilateral side production wells until breakthrough of injection fluid at the latter wells, then ceasing producing at both said closer diagonal production wells and side production wells and initiating and maintaining hydrocarbon production at the farther removed diagonal production wells until breakthrough of injection fluid thereat.

14. In the production of hydrocarbons as defined in claim 13, the additional step of again initiating and maintaining production at the quadrilateral side production wells until breakthrough again of injection fluid thereat.

References Cited

UNITED STATES PATENTS

2,885,002	5/1959	Jenks	166—9
3,113,617	12/1963	Oakes	166—9
3,205,943	9/1965	Foulks	166—9
3,286,768	11/1966	Heller	166—9
3,332,480	7/1967	Parrish	166—11

NILE C. BYERS, JR., *Primary Examiner*.