Aug. 8, 1967 H. W. PARKER 3,334,687

REVERSE IN SITU COMBUSTION PROCESS FOR THE RECOVERY OF OIL

Filed Sept. 28, 1964

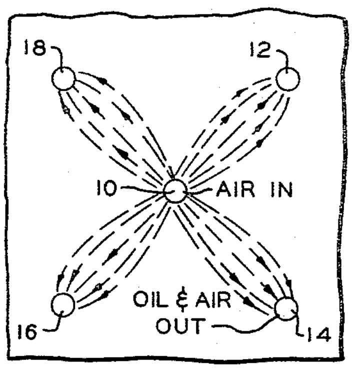

FIG. 1

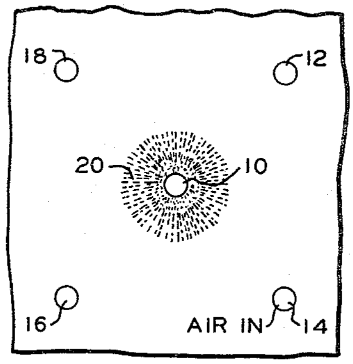

FIG. 2

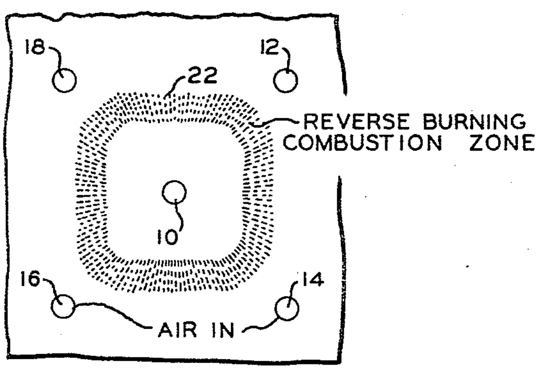

FIG. 3

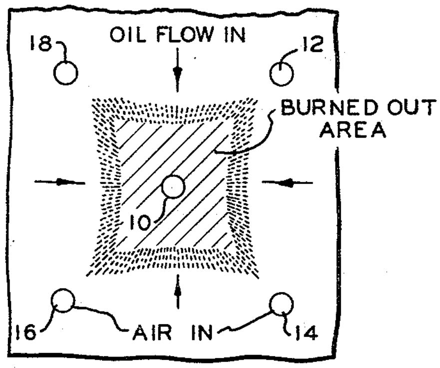

FIG. 4

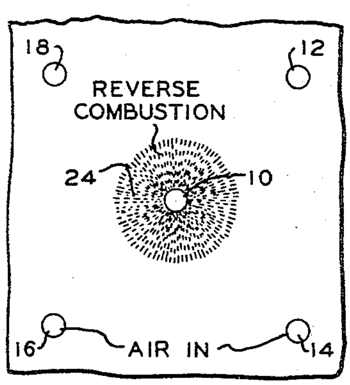

FIG. 5

INVENTOR.
H.W. PARKER

BY Young & Quigg

ATTORNEYS

United States Patent Office

3,334,687

Patented Aug. 8, 1967

3,334,687

REVERSE IN SITU COMBUSTION PROCESS FOR THE RECOVERY OF OIL

Harry W. Parker, Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware

Filed Sept. 28, 1964, Ser. No. 399,607
7 Claims. (Cl. 166—2)

This invention relates to a method for producing oil from an oil-bearing subterranean stratum by in situ combustion.

Heavy oil or tar strata are found in various areas and oil recovery therefrom is especially difficult. During primary production of such strata, the normal rate of production is too slow to render the recovery of oil economical. The low gravity of the in-place oil and the slow production thereof make it desirable to speed up production and/or to upgrade the oil prior to shipment from the field.

The instant invention is concerned with a method or process by which reverse in situ combustion can be effected prior to depletion of the reservoir pressure or as an initial primary recovery technique.

Accordingly, it is an object of the invention to provide an improved process for recovering oil from a stratum containing low gravity crude. Another object is to provide an improved in situ combustion process for the recovery of highly viscous crude oil. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises injecting air or other combustion-supporting gas into the stratum, to be produced thru a production well penetrating the stratum and producing one or more offset injection wells (preferably under a pressure at least as high as the reservoir pressure) until air appears in the produced oil and reservoir fluids. The injection thru the production well is then terminated and injection thru the injection well(s) is initiated and continued until air is produced in the production well. Thereafter, the stratum is ignited adjacent the production well by means well known in the art and injection thru the injection well(s) is continued so as to feed the combustion zone around the production well and move same toward the injection well(s) in a reverse burning process. Fuel gas may be incorporated in the injected air to facilitate ignition at the production well. After the combustion zone has been moved thru a substantial portion of the well pattern by the reverse burning step, air injection is terminated and the injection well(s) is shut-in and the back pressure on the production well is substantially reduced so as to permit invasion of oil into the well pattern from the area surrounding the well pattern. There will be some invasion of oil from the stratum immediately outside of the combustion zone when this combustion zone has not reached the injection well(s). The invading oil is heated and cracked as it enters the combustion zone and the hot burned-out area behind the combustion zone. The heated and upgraded oil is then produced by renewing air injection thru the injection well(s) while maintaining substantial back pressure on the production well to prevent further invasion of oil until after the already invaded oil has been produced. Air injection is continued thru the injection well until the injected air reaches the vicinity of the production well and renews combustion in the hot stratum which feeds on the unproduced oil resulting from the invasion. The continuance of the injection of air at this stage of the process again moves a combustion zone outwardly from the production well toward the injection well(s) and this combustion zone can be moved to the injection well(s). At this stage of the process the steps of closing in the injection well(s) and reducing the back pressure on the production well again allows oil to invade the well pattern and the combustion zone as well as the hot burned-out area behind the combustion zone and the step of producing the resulting heated and upgraded oil is repeated.

The foregoing process and repetition thereof is continued until further invasion of oil into the well pattern is so limited that the process is no longer economically feasible. At this time a well pattern in another area of the field is produced in a similar manner. It is also feasible to simultaneously conduct the in situ combustion process in several spaced-apart well patterns in the field.

The process described may be effected in any suitable well pattern such as 3-, 4-, 5-, 6-, 7-, 8-, 9-spot or similar pattern. It may also be effected between two parallel rows of wells utilized as injection wells with an intervening row of production wells. The well spacing in the pattern is preferably closer than would normally be economical for reverse combustion due to the low gravity of the oil being produced.

The termination of air injection thru the injection wells and reduction of back pressure on the production well is maintained until a substantial portion of the hot stratum has been invaded by the oil and cooled thereby. Normally, when the injected air following the invasion step breaks thru into the remaining hot stratum near the production well, countercurrent ignition occurs. In the event, there is not sufficient hot stratum about the production well for ignition when air appears at the production well, reverse ignition can be accomplished in the normal manner by again igniting the stratum adjacent the production well.

Eventually, upon repetition of the process, the reservoir pressure becomes too low for oil invasion and production into the burned stratum at an economic rate. It has been found in field operations that a 20 fold increase in permeability may occur when reverse burning is practiced and that considerable expansion of the stratum in excess of simple thermal expansion also occurs. This is probably a partial explanation of the success of repeated reverse burning of the same stratum. In strata in which the reverse combustion is practiced and which results in substantial coke deposits, the coke may be burned-out by direct or forward in situ combustion.

It is significant in the instant process that after air permeability has been established between wells in a pattern, continuous production of reversally cracked oil is maintained in a manner which utilizes the residual heat of reverse burning. This process also enables the production of natural gas in the reservoir without combustion production contaminants during the period of oil invasion of a previously burned area of the stratum.

The establishment of air permeability requires a substantial amount of time compared with such operation in a stratum containing high gravity oil, however, close well spacing is economically feasible since the wells are repeatedly used for the reverse burning operation. In obtaining air permeabiltiy, it is feasible to first inject water to dsplace the viscous oil and then displace the water with air which renders the operation more economical. Another economy in compression costs is made by using turbines to recover work from the gases produced under high back pressure at the production well.

A further embodiment of the process comprises maintaining back pressure on the production well somewhat lower than the normal formation pressure so that a portion of the stratum oil outside of the burning zone is continually fed into the burning zone from the stratum. This results in increased rates of oil production and reduced compression costs.

A further embodiment of the process comprises spacing the air injection wells sufficiently close together and injecting at a sufficiently high pressure so that little or no oil can flow into the pattern from the stratum although the production well pressure is low. Then, when the combustion front reaches the injection wells and air injection is terminated, the reverse burning continues beyond the injection wells on air stored in the stratum. After this air is exhausted, the oil flows into the hot stratum as previously disclosed and reverse burning is then repeated.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing in which FIGURES 1–5 show the various steps of the process as applied to a 5-spot well pattern.

In each of the figures, a central well **10** is surrounded by ring wells **12, 14, 16,** and **18.**

FIGURE 1 illustrates the first step of the process wherein air is injected through central well **10** and fluids are being produced through ring wells **12, 14, 16,** and **18.** In this stage of the process, water injection may precede air injection to more effectively displace oil from the well pattern and establish communication between the central well and the ring wells. Likewise, any other displacing fluid may be utilized preceding the air injection. It is also possible to perform step **1** by injecting through the normal injection wells and producing through the normal production well. This procedure requires that all of the oil within the ring of wells be produced through the central well, however, which would be a very slow operation if the oil were very viscous.

FIGURE 2 illustrates the next phase or step of the process after air is produced from the ring wells by the first step illustrated in FIGURE 1. Substantial backpressure is maintained on well **10** while injecting air through the ring wells until air is produced at well **10** at which time the oil in the stratum adjacent well **10** is ignited in conventional manner. During this air injection phase, a fuel gas such as natural gas may be incorporated in the injected air to facilitate ignition at well **10.** Burning a charcoal pack soaked with heavy oil in well **10** while injecting air containing fuel through the ring wells is a sure method of establishing a combustion zone adjacent well **10** which is identified by numeral **20.**

FIGURE 3 illustrates the next phase or step of the process wherein air injection through ring wells **12, 14, 16,** and **18** is continued after the ignition step of FIGURE 2 so as to move a combustion zone **22** radially outward from well **10** toward the ring wells within the stratum. The combustion zone **22** may be moved completely to the injection or ring wells **12, 14, 16,** and **18** or it may be moved only through a substantial portion of the well pattern before effecting the succeeding step.

FIGURE 4 illustrates the next step in the process which involves terminating injection of air through wells **12, 14, 16,** and **18** and shutting these wells in while reducing the back pressure on production well **10** thereby causing the invasion of oil into the combustion zone and the burned-out area of the stratum behind the combustion zone. This invasion of oil results in heating, cracking, and vaporizing the cracked hydrocarbons which are then produced by the step illustrated in FIGURE 5. As is shown in FIG-5, air is again injected through the ring wells so as to drive the heated and cracked hydrocarbon material resulting from the invasion of oil into the hot area of the pattern into production well **10** from which same is recovered. Continued injection of air through the ring wells results in renewing the combustion zone **24** adjacent production well **10** and further injection of air moves the resulting combusion zone by reverse drive out into the formation as in the step illustrated in FIGURE 3. The steps of FIGURES 4 and 5 are then repeated until the reservoir pressure is too low for further economical operation.

The term "substantial back pressure" on the production well when used in connection with the combustion step of this invention does not mean a particular pressure with respect to the reservoir pressure. It means a sufficient back pressure to prevent large amounts of oil from passing through the combustion zone and extinguishing it. To

illustrate, if a nine-spot pattern were used, the ring of injection wells would shield the production well from excess oil invasion and thus the production well back pressure could be low. In contrast, in using only one injection well, the back pressure on the production well would have to approach that of the reservoir to prevent oil production from extinguishing the combustion zone.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. A process for producing fuid hydrocarbons from a subterranean stratum having substantial reservoir pressure and containing a viscous crude oil, said stratum being penetrated by a well pattern including a production well and at least one offset injection well, which comprises the steps of:

(a) injecting air into said stratum thru said production well until air is produced through said injection well;

(b) thereafter, terminating injection through said production well and injecting air through said injection well so as to produce air through said production well while maintaining substantial back pressure on said production well;

(c) thereafter, igniting said stratum adjacent said production well to form a substantial combustion zone;

(d) thereafter, continuing air injection through said injection wall as in step (b) and maintaining substantial backpressure on said production well so as to feed the combustion zone of step (c) and move same into said stratum away from said production well to an area adjacent said injection well;

(e) following step (d), reducing the back pressure on said production well to substantially less than said reservoir pressure so as to allow oil flow into the combustion zone from the surrounding stratum so as to heat and fluidize the invading oil; and

(f) producing the oil fluidized by step (e).

2. The process of claim **1** wherein substantial back pressure is again applied to said production well after invading oil has occupied a substantial portion of the hot area intermediate the injection and production wells and air injection through said injection well is renewed so as to drive heated and cracked hydrocarbons into said production well; and said air injection is continued so as to ignite the stratum adjacent said production wall and a combustion zone is again moved toward said injection well with production being effected through said production well.

3. The process of claim **1** wherein step (a) is preceded by the step of injecting water into the production well and producing through the injection well under substantial back pressure until a substantial portion of the oil in the intervening stratum has been displaced.

4. A process for producing fluid hydrocarbons from a subterranean stratum containing a viscous crude oil and having substantial reservoir pressure, said stratum being penetrated by a well pattern including a central production well and a ring of offset injection wells, which comprises the steps of:

(a) injecting air into said well pattern through said central well until air is produced through said ring wells;

(b) thereafter, terminating air injection through said central well and injecting air through said ring wells, while maintaining said central well under substantial back pressure, until air is produced through said central well;

(c) thereafter, igniting said stratum adjacent said central well and feeding air to the ignited area through said ring wells so as to move the resulting combustion zone through said stratum to an area adjacent said ring wells to burn out at least a substantial portion of said well pattern;

(d) thereafter, terminating air injection through said ring wells and reducing the back pressure on said production well substantially below said reservoir pressure so as to permit oil to invade the hot zone in said well pattern thereby heating and cracking the invading oil; and

(e) thereafter, producing the heated hydrocarbons from step (d).

5. The process of claim **4** wherein step (e) comprises passing air through said pattern from the ring wells to the central well.

6. The process of claim **5** wherein combustion in said stratum is substantially terminated during step (d) and air injection in step (e) is continued until oil in the stratum is again ignited and a combustion zone is moved through said pattern toward said ring wells.

7. A process for producing fluid hydrocarbons from a subterranean stratum having substantial reservoir pressure and containing a viscous crude oil, said stratum being penetrated by a well pattern including a production well and at least one offset injection well, which comprises the steps of:

(a) injecting air into said stratum through said production well until air is produced through said injection well while maintaining substantial back pressure on said injection well;

(b) thereafter, terminating injection through said production well and injecting air through said injection well so as to produce air through said production well while maintaining substantial back pressure on said production well;

(c) thereafter, igniting said stratum adjacent said production well to form a substantial combustion zone;

(d) thereafter, continuing air injection through said injection well as in step (b) and maintaining a substantial back pressure on said production well but below the existing reservoir pressure surrounding said well pattern so as to feed and move the combustion zone of step (c) away from said production well to an area adjacent said injection well while permitting invasion of oil from the surrounding stratum into the combustion zone; and

(e) recovering the hydrocarbons produced by the foregoing steps through said production well.

References Cited

UNITED STATES PATENTS

2,788,071	4/1957	Pelzer	166—11
3,004,595	10/1961	Crawford et al.	166—11
3,076,505	2/1963	Pryor	166—11
3,110,345	11/1963	Reed et al.	166—11
3,115,928	12/1963	Campion et al.	166—11
3,232,345	2/1966	Trantham et al.	166—11 X

CHARLES E. O'CONNELL, *Primary Examiner.*

ERNEST R. PURSER, STEPHEN J. NOVOSAD, *Examiners.*