June 2, 1959 H. W. PARKER 2,888,987

RECOVERY OF HYDROCARBONS BY IN SITU COMBUSTION

Filed April 7, 1958

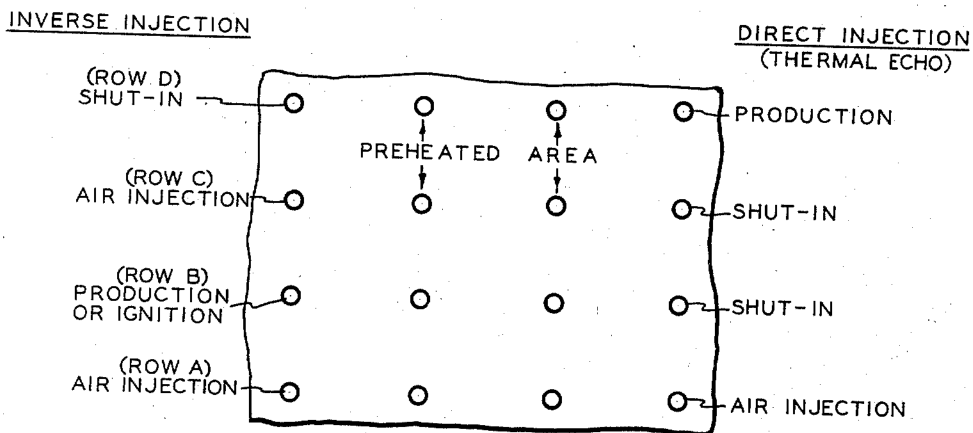

FIG. 1

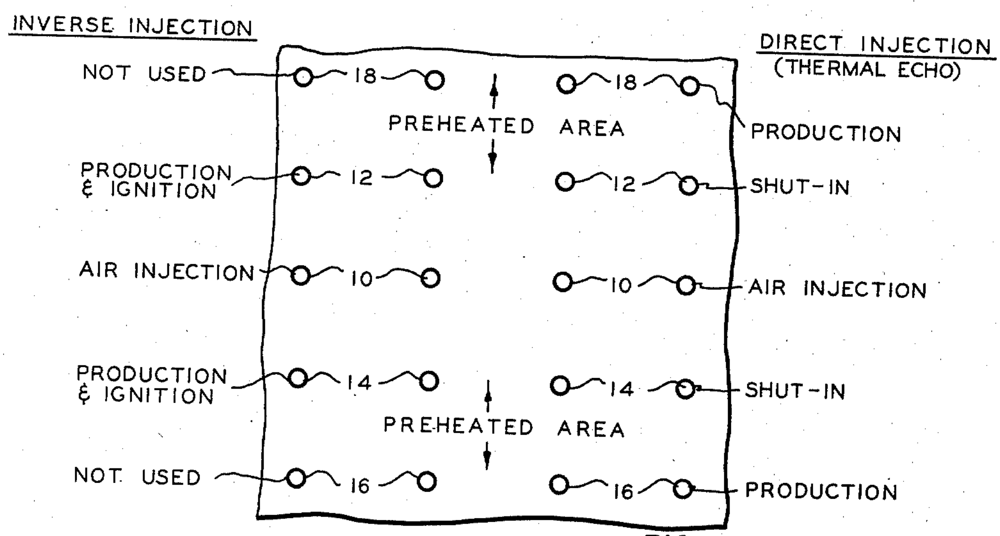

FIG. 2

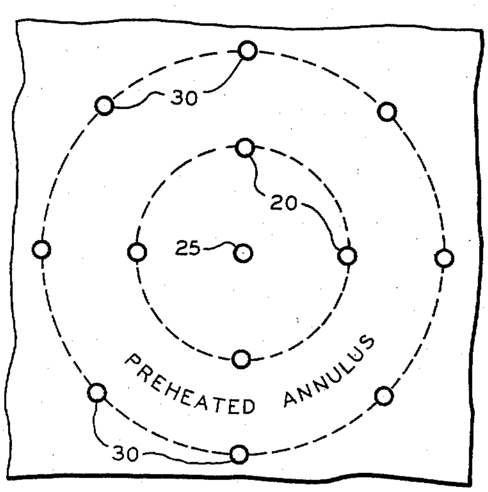

FIG. 3

INVENTOR.
H.W. PARKER

BY Hudson & Young

ATTORNEYS

United States Patent Office

2,888,987

Patented June 2, 1959

2,888,987

RECOVERY OF HYDROCARBONS BY IN SITU COMBUSTION

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

Application April 7, 1958, Serial No. 726,781

8 Claims. (Cl. 166—2)

This invention relates to an improved process for recovery of hydrocarbons from a stratum containing combustible carbonaceous material by in situ combustion.

In situ combustion the recovery of hydrocarbons from underground strata containing carbonaceous material is becoming more prevalent in the petroleum industry. In this technique of production, combustion is initiated in the carbonaceous stratum and the resulting combustion zone is caused to move thru the stratum by either inverse or direct air drive whereby the heat of combustion of a substantial proportion of the hydrocarbon in the stratum drives out and usually upgrades a substantial proportion of the unburned hydrocarbon material.

The ignition of carbonaceous material in a stratum around a borehole therein followed by injection of air through the ignition borehole and recovery of product hydrocarbons and combustion gas thru another borehole in the stratum is a direct air drive process for effecting in situ combustion and recovery of hydrocarbons from the stratum. In this type of operation the stratum usually plugs in front of the combustion zone because a heavy viscous liquid bank of hydrocarbon collects in the stratum in advance of the combustion zone which prevents movement of air to the combustion process. To overcome this difficulty and to permit the continued progress of the combustion zone thru the stratum, inverse air injection has been resorted to. By this technique, a combustion zone is established around an ignition borehole by any suitable means and air is fed thru the stratum to the combustion zone from one or more surrounding boreholes.

The present invention utilizes a combination of inverse and direct injection of air (or other O_2-containing, combustion-supporting gas) in such a manner as to effect substantially complete depletion of the stratum and to preheat a section of unburned stratum prior to the in situ combustion thereof.

It is accordingly an object of the invention to provide an improved process for the recovery of hydrocarbons from carbonaceous strata by in situ combustion. Another object is to provide an improved in situ combustion technique which preheats a selected portion of a carbonaceous stratum prior to effecting in situ combustion therein. A further object is to provide an in situ combustion process which effects substantially complete depletion of a produced stratum. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises moving a combustion front thru a carbonaceous stratum from an ignition borehole therein to an adjacent injection borehole in an inverse burning phase which leaves carbonaceous residue in the stratum thru which the combustion front initially passes and, when the combustion front arrives at the injection borehole, effecting a direct burning phase on the residual carbonaceous material by continuing the injection of air thru the injection borehole so as to reverse the movement of the combustion front and

drive the same back to the ignition borehole; however, during the direct drive of the combustion front the ignition borehole is shut-in and hydrocarbons produced during the direct burning phase are recovered thru a production borehole beyond the ignition borehole in an unburned section of the stratum whereby said unburned section between said ignition borehole and the production borehole is preheated preparatory to recovery of hydrocarbons therefrom by in situ combustion. In this manner the section of stratum traversed twice by the combustion front, once during the inverse burning phase and once during the direct burning phase, is completely denuded of carbonaceous material and a virgin section of stratum is preheated preparatory to recovery of hydrocarbon by in situ combustion.

The invention will be better understood by reference to the accompanying drawing of which Figures 1 and 2 are plan views of in-line well patterns for effecting different embodiments of the invention; and Figure 3 is a plan view of a ring type pattern of wells around a central well for effecting another embodiment of the invention.

Referring to Figure 1, four lines or rows of wells A, B, C, and D are drilled in a carbonaceous stratum such as an oil sand, tar sand, and oil shale, or a coal vein. In strata which have little or no permeability, horizontal fracturing of the stratum is essential to production in accordance with the invention. The inverse burning phase of the process as effected in the well pattern of Figure 1, comprises initiating combustion around each of the wells in row B, which are designated production or ignition wells, and injecting air or other combustion supporting gas thru the injection wells in rows A and C so as to move the combustion fronts from the wells of row B in both directions toward the wells in rows A and C countercurrently or inversely to the injected air. In this phase of the process the wells in row D are shut-in. Hydrocarbons produced during the inverse burning phase are recovered in conventional manner from the wells in row B. This burning phase leaves a coked residue in the stratum which can be burned in a direct burning phase.

The direct burning or "thermal echo" phase occurs when the combustion front arrives at the wells in rows A and C. If the injection of air thru the wells in rows A and C is continued after the combustion front arrives, the direction of the front is reversed and the same travels back towards the initial production wells in row B, feeding upon the residual carbonaceous material or coke which always remains after passage of an inverse air injection combustion front thru a stratum. Instead of injecting air thru the wells in row C upon arrival of the combustion front, these wells are shut-in and the combustion ceases in this area; however, injection of air thru the wells in row A is continued so that the combustion front along this line of wells is reversed and is driven by direct air drive back thru the stratum thru which the inverse air injection front passed; and the produced hydrocarbons during this direct air injection phase of the process are recovered thru the line of wells in row D, opened for this purpose. In this manner the virgin stratum intermediate the wells in row C and those in row D is preheated preparatory to effecting recovery of hydrocarbons therefrom by in situ combustion. When the "thermal echo" combustion front moved by direct drive reaches the wells in row C, these wells are reopened and are used as production wells while air is injected thru the wells in row D so as to move the combustion front from the line of wells in row C to the line of wells in row D inversely to the movement of air. When the combustion front arrives at the wells in row D the same may be driven back to the wells in row C thru the carbonized stratum, thereby completely denuding the stratum within the pattern shown between the line of wells in row

D and the line of wells in row E. Another selected section of the stratum adjacent the section shown can then be produced in a similar manner.

Another embodiment of the invention is illustrated in Figure 2 wherein in-line wells 12 and 14 are utilized as ignition and production wells with air being injected thru the line of wells 10 so that the combustion front moves from each line of wells 12 and 14 to injection wells 10, where upon continued injection of air thru wells 10 the movement of the combustion front is reversed and feeds upon the carbonized residue left by the inverse burning phase. During this direct drive or "thermal echo" phase of the process, ignition or production wells 12 and 14 are shut-in so that the hot product gases pass thru the area of the stratum intermediate the line of wells 14 and the line of wells 16 and also intermediate the line of wells 12 and the line of wells 18. Upon arrival of the combustion front at wells 12 and 14, these wells are reopened and are utilized as production wells while air is injected thru wells 16 and 18 so as to move the combustion fronts by inverse injection thru the unburned sections of stratum which have just been preheated. Here again, continued injection of air thru wells 16 and 18 after the combustion front arrives at these wells drives the combustion front back to wells 14 and 12 from wells 16 and 18, respectively.

The embodiment of the process illustrated in Figure 3 comprises igniting the stratum around boreholes 20 by any suitable means, injecting air thru central borehole 25, and producing thru boreholes 20 whereby the combustion front moves toward borehole 25 leaving a coked residue in the stratum thru which it travels. When the combustion front reaches borehole 25 it is reversed by continued injection of air thru the central borehole to initiate a direct burning phase of the process. During this direct burning phase, the boreholes 20 are shut-in and the hot production gases are recovered thru a ring of production boreholes 30 outside of the ring of boreholes 20 thereby preheating the annular section between the two rings of boreholes so that when the combustion front on the direct burning phase reaches the ring of boreholes 20 air is injected thru boreholes 30 so as to continue the movement of the combustion front from ring 20 outwardly to ring 30 by inverse burning. Upon initiation of air injection thru the boreholes in ring 30, boreholes 20 which were shut-in during the direct burning phase may be re-opened and utilized as production boreholes and it is also feasible to keep these boreholes shut-in and produce thru central borehole 25.

It is also feasible to open another row or ring of wells beyond row D or ring 30 when the combustion front arrives and inject air therethru so as to move the combustion front thru an additional section of stratum before instituting a direct burning phase from the newly opened wells back to the wells in row C or ring 30.

The well spacing to be utilized in the various embodiments of the invention will depend upon the type and permeability of the stratum to be produced. The space between adjacent wells or rows of wells will vary from a few feet such as 5 to 10 feet up to 50, or more.

Plugging of the formation during the direct burning phase in which the hot produced gases pass thru a virgin section of stratum is less apt to occur when the space between the wells in the virgin section and the adjacent well or wells in the edge of the produced section is short. In any event the spacing to be utilized must be determined by the permeability of the stratum and the character of the carbonaceous material therein.

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 hydrocarbons from a stratum containing combustible carbonaceous material

which comprises moving a combustion front from an ignition borehole to an injection borehole in said stratum in an inverse burning phase by igniting said stratum at said igniton borehole and passng O_2-containing gas thru said stratum to the resulting combustion front; when said combustion front arrives at said injection borehole, effecting a direct burning phase on residual carbonaceous material by continuing the injection of said gas to reverse the movement of said front; shutting-in said ignition borehole; and recovering hydrocarbons produced by said direct burning phase thru a production borehole beyond said ignition borehole in an unburned section of said stratum so as to preheat same preparatory to recovery of hydrocarbons therefrom by in situ combustion thereof.

2. The process of claim 1 further comprising reopening the shut-in ignition borehole as said combustion front arrives there during the direct burning phase; then injecting said gas thru said production borehole to establish a second inverse burning phase whereby said combustion front moves toward said production borehole; and recovering hydrocarbons produced by said second inverse burning phase thru said ignition borehole.

3. A process for producing hydrocarbons from a stratum containing combustible carbonaceous material which comprises, in a first burning phase leaving residual carbonaceous material, moving combustion fronts from a first line of production boreholes outwardly therefrom in both directions to lines of gas injection boreholes, one on each side of the line of production boreholes and generally parallel thereto, by inverse injection of an O_2-containing gas thru said injection boreholes; recovering produced hydrocarbons thru aforesaid production boreholes; after said combustion fronts arrive at said lines of injection boreholes and while the fronts are at combustion supporting temperature, shutting-in one line of injection boreholes and said line of production boreholes; injecting said gas thru the other line of injection boreholes in a second burning phase feeding on said residual material so as to drive another combustion front back thru the partially burned out stratum to the shut-in line of injection boreholes; and recovering produced hydrocarbons during said second burning phase thru a second line of production boreholes generally parallel to and beyond said shut-in lines of injection boreholes, whereby the unburned section of said stratum intermediate said shut-in line of boreholes and said second line of production boreholes is preheated for in situ combustion recovery.

4. The process of claim 3 wherein said gas is air.

5. The process of claim 3 including the steps of reopening said shut-in line of injection boreholes after the combustion front has arrived during the second burning phase; injecting said gas thru said second line of production boreholes so as to feed the combustion front just arrived at the line of reopened boreholes; and recovering produced hydrocarbons from the line of reopened boreholes.

6. A process for producing hydrocarbons from a stratum containing combustible carbonaceous material which comprises moving combustion fronts from a ring of ignition and production boreholes to a central injection borehole in an inverse burning phase by injection of O_2-containing gas thru said central borehole while withdrawing produced hydrocarbons thru said ring of boreholes; when said combustion front arrives at said central borehole, effecting a direct burning phase on residual carbonaceous material by continuing injection of said gas thru said central borehole so as to drive the combustion front to said ring of boreholes; during said direct burning phase, closing in said ring of boreholes and recovering produced hydrocarbons from an outer ring of boreholes whereby the stratum intermediate the rings of boreholes is preheated preparatory to recovery of hydrocarbons therefrom by in situ combustion.

7. The process of claim 6 further comprising opening the ring of shut-in boreholes as said combustion front arrives there during the direct burning phase; then injecting said gas thru the outer ring of boreholes to establish a second inverse burning phase whereby said combustion front moves outwardly to said outer ring of boreholes; and recovering hydrocarbons produced by said second inverse burning phase from inner wells.

8. The process of claim 7 further comprising injecting said gas thru an outermost ring of boreholes when said combustion front arrives at said outer ring of boreholes so as to continue said second inverse burning phase until said front arrives at said outermost ring of boreholes; recovering hydrocarbons produced during the continuation of said second burning phase thru inner boreholes; after said combustion front arrives at said outermost ring, continuing injection of said gas thru said outermost ring so as to reverse its movement and drive same back to said inner ring of boreholes as a second direct burning phase; and recovering produced hydrocarbons during said second direct burning phase thru inner boreholes ahead of the combustion front.

References Cited in the file of this patent

UNITED STATES PATENTS

2,347,778	Heath	May 2, 1944
2,793,696	Morse	May 28, 1957