Aug. 1, 1961 F. W. CRAWFORD ET AL 2,994,376

IN SITU COMBUSTION PROCESS

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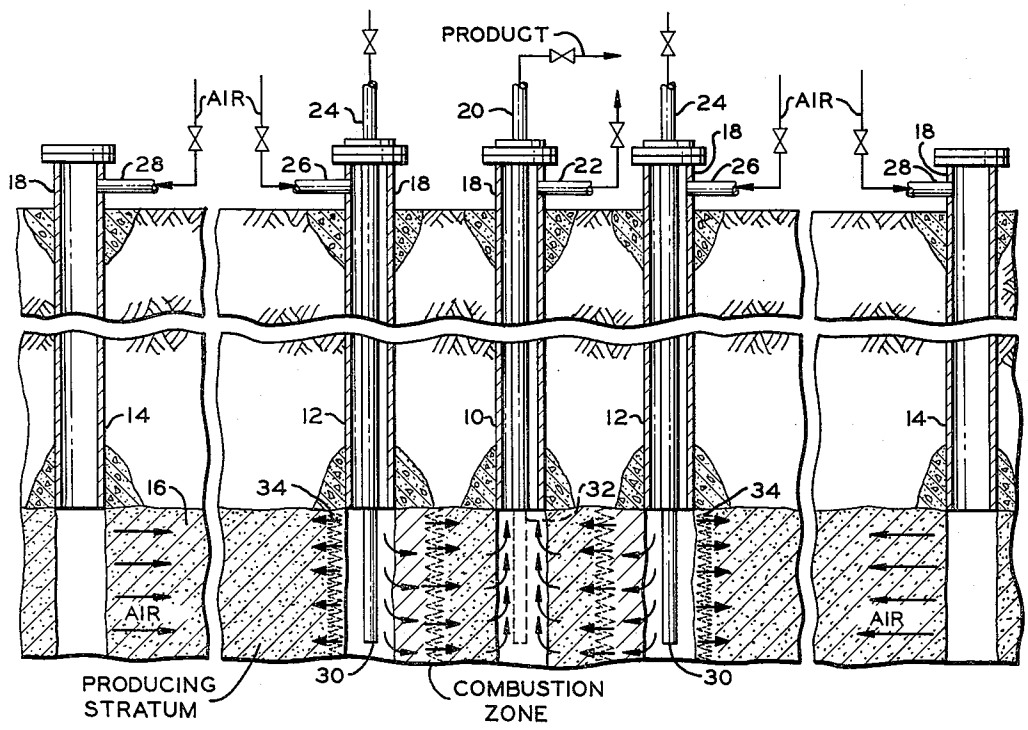


FIG. 2

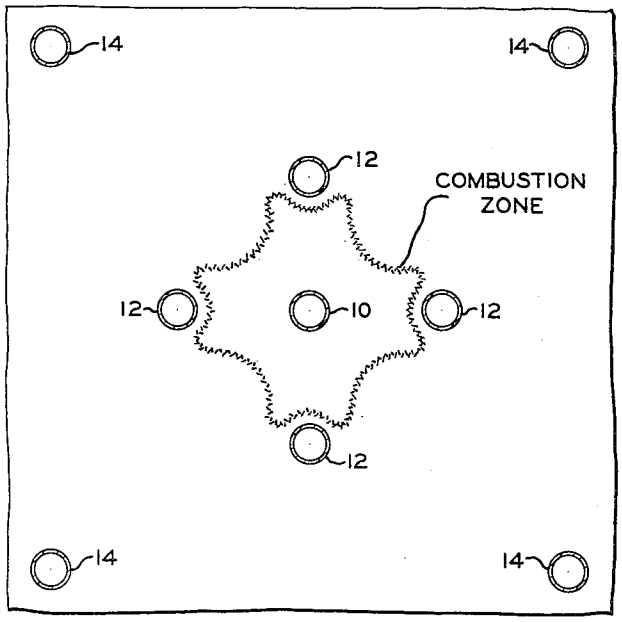


FIG. 1

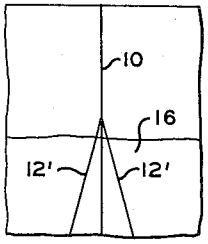


FIG. 3

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This invention relates to a process for recovering hydrocarbons from carbonaceous strata by in situ combustion. A specific aspect of the invention relates to a method of initiating in situ combustion for inverse air injection type of in situ combustion in a carbonaceous stratum.

In situ combustion in 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 remaining hydrocarbon material. The ignition of carbonaceous material in a stratum around a borehole therein followed by injection of air thru 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 becomes plugged in front of the combustion zone because a heavy viscous fluid bank collects in the stratum in advance of the combustion zone which prevents movement of air to the combustion process. To overcome this difficulty and 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 produced hydrocarbons pass thru the hot more permeable area behind the combustion front thereby avoiding the formation of a viscous fluid bank of hydrocarbon material in the stratum.

In initiating inverse air injection to advance a combustion zone in a carbonaceous stratum considerable difficulty in establishing a self-sustaining combustion has been experienced. The conventional technique comprises passing air thru the stratum to the ignition borehole and simultaneously heating the borehole to a combustion supporting temperature. Because of the flow of air into the borehole in which the heat is produced it has been difficult to heat up a sufficient area or section of the stratum around the borehole to establish a self-sustaining process. Much of the heat passes away from the area to be heated. Another problem resulting from this type of operation lies in the tendency to melt or otherwise damage downhole equipment including the downhole burner. A large percent of the heat from the heating device in the borehole is carried out of the borehole with excessive heating of the downhole equipment.

In another type of operation air is injected thru the ignition borehole and after ignition has been effected, the flow of air is reversed. Unless a large area is ignited prior to reversal the fire usually goes out and is not revived when air again arrives in the ignition area. If too large an area is heated there is danger of plugging because of direct drive.

This invention is concerned with a method or technique of operation which permits utilizing of inverse air injection and avoids the problems just enumerated.

Accordingly, a principal object of the invention is to provide an improved process for producing hydrocarbons from a carbonaceous stratum by in situ combustion utilizing inverse air injection. Another object is to provide an improved method of initiating in situ combustion in a carbonaceous stratum as an initial step in the inverse air injection type process. A further object is to provide a method of initiating inverse air injection in situ combustion in a carbonaceous stratum which conserves heat and which avoids heat damage to downhole heating equipment. It is also an object of the invention to provide an improved method of initiating inverse air injection in situ combustion which avoids the necessity of reversing air flow in the initial stages of the process. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

In accordance with the invention, the principal well which is to serve either as an air injection well for conventional direct drive combustion or as a production well for countercurrent or inverse air drive in situ combustion is drilled in its normal position in the well pattern and one or more auxiliary air injection wells are drilled in the immediate vicinity, within a few feet of the principal well, preberably in a ring around the same. One or more primary injection wells are drilled in a more remote location such as 25 to 1,000 feet or more from the principal well. In accordance with one embodiment of the invention, the walls of the auxiliary injection boreholes are heated by any suitable means to combustion-supporting temperature and air or other free-oxygen-containing gas such as oxygen-enriched air is injected into the stratum thru the auxiliary boreholes. Air may also be injected into the primary injection boreholes so as to force the injected air to the central or principal well which serves in this embodiment as a production well. The injection of air thru the hot auxiliary boreholes establishes combustion of the carbonaceous material in the stratum and the combustion zone is driven by direct air drive toward the production well. Because of the injection of air thru the primary injection wells the combustion zone, established by the easier method of direct injection around the central well, is moved outwardly from the auxiliary wells countercurrently to the flow of air and a self-sustaining in situ combustion is thereby established rather easily, because of the large combustion area and heat reservoir established by the direct air injection technique.

The auxiliary wells are spaced relatively close to the central well so that direct drive of the combustion zone does not plug the stratum between the auxiliary wells and the central well. This distance can be made anywhere in the range of 1 to 10 feet depending upon the character of the hydrocarbon material in the stratum and the permeability thereof. If plugging difficulty is encountered heat can be applied to the stratum at the wall of the central borehole so as to lower the viscosity of the fluid hydrocarbon released in the stratum by the combustion process. However, in most applications of the technique described herein, heating of the central borehole is unnecessary as the flow path between the auxiliary wells and the central well is so short and little cooling of the hydrocarbons released from the formation by the combustion takes place therein.

After the combustion zone is well established around the central well, injection air thru the auxiliary boreholes is terminated and these boreholes are either sealed off so that all of the production is removed thru the central well or produced hydrocarbons may be recovered from any or all of these boreholes with continued injection of air thru the primary injection wells.

In accordance with another embodiment of the invention, the borehole around the central well is heated to

combustion supporting temperature and air or other oxygen-containing gas is passed thru the stratum to the hot section thereof from the auxiliary and primary injection boreholes. In this manner, ignition of the carbonaceous material in the stratum immediately surrounding the central borehole is achieved and the combustion zone thus established moves outwardly toward the auxiliary boreholes. When the combustion zone reaches the auxiliary boreholes, continued injection thru these boreholes has the effect of reversing the combustion zone and driving the same back to the central well so that, even though injection of air thru the primary injection wells is continued during this phase of the operation, there is danger of the combustion dying out after reversal of the movement of the zone between the central well and the auxiliary wells. In order to facilitate the operation and assure establishment of the inverse air injection process with movement of the combustion zone toward the primary injection wells, the injection of air thru the auxiliary wells is terminated as the combustion zone approaches these wells and air is injected thru the central well, instead, with production being removed from the auxiliary wells. In this manner the movement of the combustion zone past the auxiliary wells is effected by direct air drive which avoids the possibility of reversal of the combustion zone. The carbonaceous residue produced by the first passage of the combustion zone thru the formation is recovered by the second combustion wave or reflection burning which takes place when the combustion zone reaches the primary injection wells and the injection of air therethru is continued.

The heating of the stratum around either the auxiliary injection wells or the central production well in accordance with either embodiment of the invention may be effected by any suitable means, such as by means of electric or gas-fired heater, by burning any solid or liquid fuel in the borehole, or by pyrotechnics. By heating the wells of the borehole up to combustion supporting temperature in the presence of air, such as a temperature in the range of about 450 to 750° F., or higher, and by injecting air into the hot formation, either thru the heated borehole or thru the stratum to the heated borehole from an adjacent borehole, ignition of the carbonaceous material in the stratum is readily effected. If ignition of the carbonaceous material at lower temperatures is desired, the same may be effected by contacting the hot formation with pure oxygen or oxygen-enriched air.

A more complete understanding of the invention may be obtained by reference to the accompanying schematic drawing of which FIGURE 1 is a plan view showing a typical well spacing for effecting the process of the invention; FIGURE 2 is an elevation showing an arrangement of wells and apparatus penetrating a carbonaceous stratum in accordance with the invention; and FIGURE 3 is an elevation showing a central borehole with auxiliary air injection boreholes drilled from the central borehole.

Referring to FIGURE 1, a central production well **10** is surrounded by auxiliary injection wells **12** in a ring pattern closely spaced from well **10**. Primary injection wells **14** are also spaced in a ring pattern around the central well but considerably more remote therefrom than wells **12**. In FIGURE 2, wells **10**, **12**, and **14**, which may be in line (as in FIGURE 2) or not in line (as in FIGURE 1) penetrate a carbonaceous stratum **16**. Each of the wells is provided with a casing **18** extending to the upper level of stratum **16**. Well **10** is provided with a tubing **20** and with a line **22** for withdrawing and injecting gas at different stages of the process. Wells **12** are similarly equipped with tubing **24** and line **26** for injecting and withdrawing gases from the wells. Primary injection wells **14** are provided with air injection lines **28**. In the embodiment of the invention illustrated in FIGURE 2, a heating means **30** is positioned on the lower end of tubing **24** in wells **12** for the purpose of heating the stratum around the boreholes to combustion supporting temperatures. (In the event another embodiment of the invention is utilized wherein the stratum around borehole **10** is heated, heating element **32** is positioned in well **10**.) If the heating element is a gas-fired heater, the mixture of gas and air to supply the heater is injected thru tubing **24**. In instances where an electric heating element is utilized, the wire or wires for conducting current to the heating element are positioned in tubing **24**. In this embodiment of the invention, a combustion zone **34** is established around each of wells **12** in stratum **16**.

FIGURE 3 shows central well **10** and auxiliary air injection wells **12'** which are drilled by controlled directional drilling thru borehole **10** by conventional means. These auxiliary boreholes may be easily drilled from borehole **10** at a small angle to borehole **10** by means of a whipstock from a point 25 to 50 feet or more above stratum **16** so that boreholes **12'** are spaced within a few feet of borehole **10** thruout their passage thru the stratum. Separate tubing and heating equipment (not shown) are positioned in holes **12'** and **10** for operation similar to operation with the arrangement of FIGURE 2.

Operation in accordance with the embodiment of the invention shown in FIGURE 2 entails heating the wall of each of boreholes **12** within stratum **16** by suitable means such as by heater **30**. Simultaneously with the initiation of heating in these boreholes or after heating has been initiated, the injection of air thru boreholes **12** and **14** is commenced and continued so that as the temperature of the stratum adjacent boreholes **12** reaches combustion supporting temperature, ignition of the carbonaceous material is effected and the resulting combustion zone is expanded into the stratum so that it moves radially outwardly from the boreholes but considerably more rapidly toward production well **10** than toward injection wells **14** because of the direct drive of the combustion front in the area intermediate well **10** and wells **12**. During this phase of the operation, produced hydrocarbons and combustion gases are withdrawn thru central well **10** by means of tubing **20** and/or conduit **22**. As the combustion zone **34** is expanded and approaches the vicinity of borehole **10** a sufficiently large heat reservoir and combustion zone has been established to assure the movement of the combustion zone toward primary injection wells **14** so that when the fire dies out in the section of the stratum intermediate well **10** and wells **12** a substantial annular combustion zone between wells **12** and wells **14** is progressing toward wells **14** by inverse air injection. After the combustion front approaches or reaches well **10**, injection of air thru the auxiliary injection wells **12** is terminated and these wells may be sealed, or they may be used as production wells, along with well **10** or in lieu thereof.

In the other embodiment of the invention where ignition is initiated in the wall of borehole **10** by means of heating device **32**, the combustion front is established in the immediate area surrounding well **10** by injection of air thru wells **12** and **14** so that the resulting combustion zone moves radially outwardly from well **10** toward wells **12** and **14**. The pattern of the combustion area resulting from this operation is illustrated in FIGURE 1 which shows the faster advancement of the combustion front directly toward wells **12**. When the combustion front approaches to within a few inches to a foot of wells **12**, injection of air thru these wells is terminated and injection is switched to well **10** while continuing the injection of air thru wells **14**. In this manner, the combustion front moves into and past wells **12** without reversal of the combustion zone by reflectional burning, and the combustion zone moves on out toward wells **14**. When the combustion zone passes into wells **12**, injection of air thru well **10** is terminated and production is then recovered by conventional means thru any or all of wells **10** and **12**.

While direct drive in situ combination is generally not feasible in the average carbonaceous stratum for substantial distances betweeen boreholes, it is possible in certain types of formations where the permeability is high and the carbonaceous deposit is of the proper character to effect in situ combustion by direct air drive. In such applications of the invention after establishing a substantial heat reservoir and combustion zone around the central well, direct drive of the combustion zone to wells **14** may be effected by continuing the injection of air thru wells **12** and utilizing wells **14** as production wells while closing off well **10**. Alternatively or simultaneously air may be injected thru well **10** to supply air for driving the combustion front.

After combustion has been established, either by means of heaters in well **10** or in wells **12**, the downhole heating equipment is preferably removed and the same is replaced with conventional production equipment in instances where these wells are to be utilized as production wells.

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.

We claim:

1. A process for recovery of hydrocarbons from a carbonaceous stratum by in situ combustion which comprises initiating combustion of the carbonaceous material in a section of said stratum intermediate a production borehole and at least one auxiliary injection borehole spaced from one to a few feet therefrom by heating said section to combustion-supporting temperature and contacting same with free-oxygen-containing gas; injecting free-oxygen-containing gas thru said auxiliary injection borehole and also thru at least one primary injection borehole spaced farther from said production borehole so as to feed oxygen to the resulting combustion zone and cause same to move toward said primary injection borehole countercurrent to the flow of said gas; and recovering thru said production borehole hydrocarbons driven from said stratum by the combination process.

2. The process of claim 1 wherein combustion is initiated by heating said stratum around said auxiliary injection borehole to ignition temperature whereby the combustion zone is advanced by direct drive toward the production borehole and by inverse drive toward said primary injection borehole.

3. The process of claim 1 wherein combustion is initiated by heating said stratum around said production borehole to ignition temperature whereby the combustion zone is advanced outwardly therefrom toward the injection boreholes.

4. A process for recovery of hydrocarbons from a carbonaceous stratum by in situ combustion which comprises initiating combustion of the carbonaceous material around a production borehole in said stratum; moving the resulting combustion zone radially outwardly from said production borehole by injecting free-oxygen-containing gas into at least one auxiliary injection borehole in said stratum spaced from 1 to 10 feet from said production borehole so as to force said gas to said combustion zone; withdrawing production thru said production borehole during the preceding step; as the combustion zone approaches said auxiliary injection borehole, discontinuing the injection of said gas thru said auxiliary injection borehole and injecting free-oxygen-containing gas into said stratum thru said production borehole and thru at least one primary injection borehole radially outside of said auxiliary injection borehole so as to move said combustion zone past said auxiliary borehole and prevent reflection burning; and recovering production thru said auxiliary borehole during the preceding step.

5. The process of claim 4 wherein injection of said gas thru said production borehole is terminated after said combustion zone moves radially outside of said auxiliary borehole.

6. The process of claim 5 wherein recovery of production thru said production borehole is resumed after termination of injection therethru.

7. The process of claim 4 wherein air is injected simultaneously thru said auxiliary and said primary injection boreholes to move the combustion zone from the proximity of said production borehole to said auxiliary injection borehole.

8. A process for recovery of hydrocarbons from a carbonaceous stratum by in situ combustion which comprises drilling a central production borehole, a plurality of auxiliary injection boreholes surrounding said production borehole within the range of about one to 10 feet therefrom, and a plurality of more remote primary injection boreholes surrounding aforesaid boreholes; heating said stratum intermediate said auxiliary injection boreholes and said production borehole to ignition temperature; feeding free-oxygen-containing gas to the heated stratum thru said primary and said auxiliary injection boreholes so as to ignite carbonaceous material in said stratum and move the resulting combustion zone toward said primary injection boreholes countercurrent to the flow of said gas; and recovering produced hydrocarbons from said stratum.

9. The process of claim 8 wherein said auxiliary injection boreholes are drilled by controlled directional drilling thru said production borehole and said gas fed to said auxiliary boreholes is introduced thereto thru said production borehole.

10. The process of claim 8 wherein combustion is initiated around each auxiliary injection borehole so that the resulting combustion zone is advanced to said production borehole by direct drive and toward said primary injection boreholes by inverse drive.

11. The process of claim 8 wherein combustion is initiated in the wall of said production borehole, the resulting combustion zone is advanced toward said auxiliary injection boreholes, and as said zone approaches said auxiliary injection boreholes, discontinuing the injection of gas thru last said boreholes, injecting free-oxygen-containing gas thru said production borehole, and recovering production thru said auxiliary injection boreholes.

12. The process of claim 11 where injection of said gas thru said primary injection boreholes and said production borehole is continued until the combustion zone is moved radially outwardly beyond said auxiliary injection boreholes and, thereafter, injection thru said production borehole is terminated, said auxiliary boreholes are closed, and production is recovered thru said production borehole.

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