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IN SITU COMBUSTION METHOD

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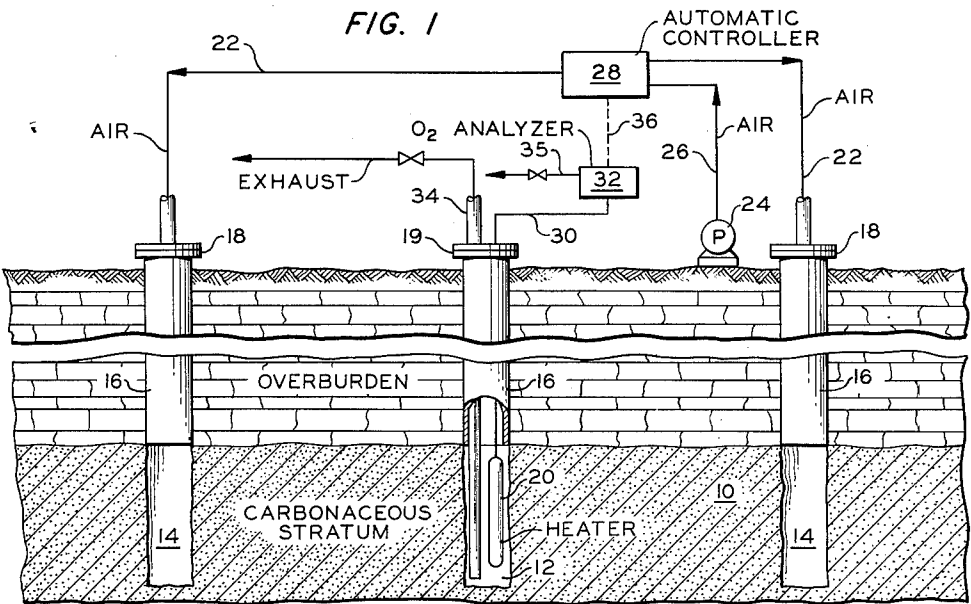


FIG. 3

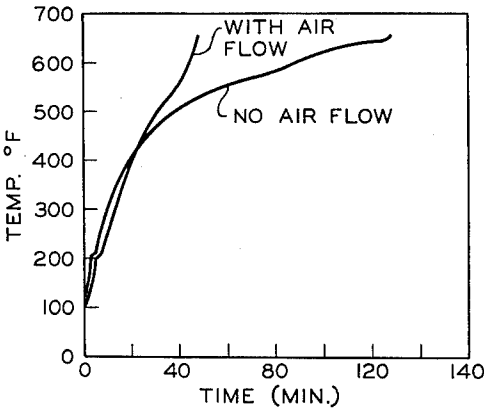
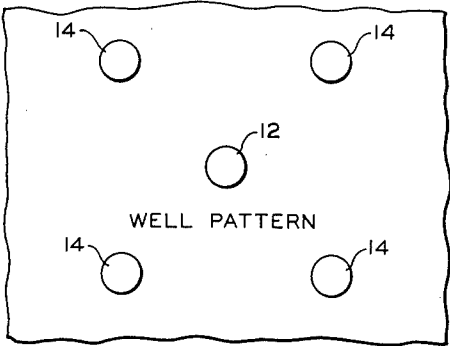


FIG. 2

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ATTORNEYS

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3,032,102

IN SITU COMBUSTION METHOD

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13 Claims. (Cl. 166-11)

This invention relates to an improved process for initiating 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 plugs 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.

In operating with either direct or indirect air injection to produce hydrocarbons from a carbonaceous stratum by in situ combustion, it is necessary to first ignite the carbonaceous material in the stratum around a borehole therein. One method of ignition utilizes a downhole heater of either the electric or gas fired type to heat the wall of the ignition borehole and an annular section of the stratum surrounding the borehole. Another technique comprises placing charcoal in the ignition borehole adjacent the stratum to be ignited and burning the charcoal therein by igniting same while feeding O₂-containing gas thereto. In any of these processes for igniting the carbonaceous stratum, a long preheating period is necessary to bring the temperature thereof up to ignition temperature, which is usually in the range of about 550 to 700° F. when contacting the hot stratum with air as the O₂-containing gas. This invention is concerned with a method whereby the preheating period is substantially reduced.

Accordingly, the principal object of the invention is to provide an improved process for initiating combustion in a carbonaceous stratum. Another object is to reduce the preheating period required prior to the ignition of a carbonaceous stratum. A further object is to provide an improved method of controlling the ignition of a carbonaceous stratum to be produced by in situ combustion. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises heating a section of a stratum containing combustible carbonaceous material to bring the same to ignition temperature and, while preheating said section, contacting the same with a stream of O₂-containing gas under controlled flow conditions.

Air or other O₂-containing gas is passed to the section

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of stratum being heated during the heating step, at a slow rate during the initial phases of the preheating and at a faster rate during the later phases thereof. The flow of air to the preheated area is regulated by analyzing the effluent therefrom for either O₂ or CO₂ and by controlling the rate of air flow so as to maintain the O₂ concentration in the range of about 0.10 to about 10% by volume; or, when analyzed for CO₂ concentration, regulating the flow to maintain the concentration of CO₂ in the range of about 6 to 13 or 14% by volume. If the O₂ concentration in the effluent exceeds the desired upper limit in the range of 0.10 to 10% by volume or if the concentration of CO₂ in the effluent gas falls below a minimum in the range of 6 to 14% by volume, the flow rate of air thru the stratum is decreased to bring the concentration of O₂ or CO₂ to a level in the preceding ranges. Conversely, if the O₂ concentration in the effluent gas falls below a minimum in the range of 0.10 to 10% by volume, or if the CO₂ concentration in the effluent gas exceeds a maximum in the range of 6 to 14% by volume, then the rate of flow of air thru the heated stratum is increased. In other words, the concentration of either O₂ or CO₂ in the effluent gas is determined and the flow rate of air is controlled so as to maintain the concentration of these constituents in the above ranges.

It has been found that by contacting the heated section of stratum during the preheating step with O₂ and controlling the flow of O₂ so as to maintain a low oxygen concentration (and high CO₂ concentration) in the effluent from the heated section, the time required for establishing ignition of the stratum can be reduced at least in half. By this method the allowable rate of flow of O₂ continuously increases during the preheating thus permitting self-sustaining ignition to start without the sudden shock of operating the ignition well after a long period of being shut in and the associated problems of flashing water to steam or a sudden rush of cold tar and water into the heated zone, particularly, when the inverse air injection method is utilized, with the ignition well serving as a production well.

It has been found that slow oxidation occurs during the early phases of the preheating step when air is fed to the heated area and, as the temperature of the stratum rises, the rate of oxidation increases. For this reason, it is feasible to preheat the section of stratum around an ignition borehole therein to raise the temperature thereof to about 200 to 300° F. (such as 250° F.) before contacting the same with a stream of air. However, air may be flowed to the section of stratum during the entire preheating period at increasing rates, as required to maintain the proper oxygen concentration in the effluent, so that when the ignition temperature is reached, ignition is automatically effected. In cases where a heating device is utilized for the preheating step, the same is removed when ignition is established.

Control of the O₂ or CO₂ concentration in the effluent from the section of stratum being heated automatically determines the air flow rate at any given time. Flow rates will vary widely during the preheating period probably because of the changing rate of oxidation of carbonaceous matter.

A rate as low as 1 or 2 standard cubic feet per hour per square foot of well bore area in the carbonaceous stratum comes within the scope of the process and rates will go as high as 200 s.c.f.h. per square foot of borehole area and higher, depending upon the permeability of the stratum and the character of the carbonaceous deposit therein.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is an elevation showing an arrangement of apparatus in association with a carbonaceous

aceous stratum for effecting the process of the invention; FIGURE 2 shows a typical 5-spot well pattern adapted to the process of the invention; and FIGURE 3 is a graph showing the relation between time and preheat temperature in preheating a section of carbonaceous stratum with and without air flow.

Referring to FIGURE 1, a carbonaceous stratum 10 is penetrated by an ignition borehole 12 and a number of injection boreholes 14 two of which are shown. Boreholes 14 are spaced, as shown in FIGURE 2, around borehole 12 in a generally annular pattern and spaced therefrom any suitable distance within the range of a few feet to several hundred feet, depending upon the permeability of the carbonaceous stratum and other factors. It is to be understood that, where the permeability is low, the stratum may be horizontally fractured in known manner.

Each well is provided with a casing 16 and a well head 18. A heater 20 is positioned in borehole 12 within stratum 10 so as to heat the wall of the borehole within the carbonaceous stratum. Heater 20 may be of any type such as a gas fired heater, an electric heater, or a mass of incandescent charcoal. One type of gas fired heater which has been found particularly effective is that disclosed and claimed in the U.S. application of A. S. Rogers et al., Serial No. 719,890, filed March 7, 1958. Charcoal has also been found to be very effective in preheating a carbonaceous stratum surrounding a borehole for in situ combustion purposes.

Air lines 22 connect with each injection well head 18 and with a source of air supply, such as blower 24, thru line 26. An automatic controller 28 is positioned in the air line circuit between line 26 and lines 22 to control the amount of air passing to the air injection wells. An effluent line 30 from well head 18 of ignition well 12 connects with an analyzer 32 which is provided with an exhaust line 35. Analyzer 32 is operatively connected with automatic controller 28 via line 36. Tubing 34 serves as an exhaust and as production tubing.

Analyzer 32 may be any oxygen analyzer or CO₂ analyzer of any construction or design which satisfactorily analyzes the effluent gas for O₂ or CO₂ concentration. The analyzer may be of the paramagnetic, conductive bridge type, or of the well known absorbent type. A Beckmann paramagnetic oxygen analyzer has been found very satisfactory in field tests in in situ combustion. It is also feasible to periodically analyze the effluent gas by well known laboratory methods to determine either the O₂ content or the CO₂ content and periodically regulate the flow of air or other O₂-containing gas to the injection wells so as to maintain the O₂ or CO₂ concentration in the effluent within the desired ranges or at a substantially constant value within said ranges. However, automatic continuous analyzers and controllers are available from commercial sources for effecting the controls of the process.

FIGURE 3 shows curves plotted from laboratory tests on igniting tar sand on a small scale oil well arrangement. In the tests, a section of tar sand 4½ inches thick and 7 inches in diameter was clamped between two flanges so that air could be forced into the sides of the cylinder thru the cylindrical surface and produced from a well drilled along its axis. This gave a system of radial flow similar to that employed in field operations. The rock or sand was heated by means of an electric heater in the well bore. In tests in which the well bore was preheated without flow of air thru the rock during the preheating operation, the time for heating to ignition temperature was of the order of 40 minutes. In another test with the same arrangement of apparatus and tar sand, air was flowed thru the sand during the preheating operation and the effluent gas from the well bore was analyzed for carbon dioxide. (A continuous oxygen analyzer was not available in the laboratory at the time.) The flow of air was controlled to maintain a carbon di-

oxide concentration in the range of 6 to 13 percent in the effluent gas from the well bore. A temperature of 600° F. (the approximate ignition temperature) was reached approximately 2½ times as rapidly as in the tests without air flow, as measured by a thermocouple one-half inch from the well bore. The test data for the two types of runs are plotted and shown in FIGURE 3.

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 initiating in situ combustion in a carbonaceous stratum comprising preheating a section of said stratum around a borehole therein to raise same to ignition temperature; during said preheating, passing O₂-containing gas thru said section at gradually increasing flow rate from a low flow rate to a substantially higher flow rate at the time when said temperature is reached; analyzing gaseous effluent from said section to determine the concentration of a constituent thereof selected from the group consisting of O₂ and CO₂; regulating the flow rate of said gas to said section in accordance with the resulting concentration to maintain a desired concentration of said constituent in said effluent, said range being 0.10 to 10% by volume when regulating in response to O₂ concentration and 6 to 14 percent by volume when regulating in response to CO₂ concentration; continuing the preheating step until the ignition temperature of the carbonaceous material in said stratum is reached; and continuing the flow of said gas to said section so as to ignite carbonaceous material therein.

2. The process of claim 1 wherein the concentration of O₂ is used to regulate the flow of O₂-containing gas.

3. The process of claim 1 wherein the concentration of CO₂ is used to regulate the flow of O₂-containing gas.

4. A process for initiating in situ combustion in a stratum containing carbonaceous material comprising preheating a section of said stratum around a borehole therein to raise the temperature of said material to the ignition point; while the temperature of the wall of the borehole is rising thru the range of about 250° F. to about 600° F., passing a stream of air thru said section; analyzing gaseous effluent from said section to determine the concentration of a constituent thereof selected from the group consisting of O₂ and CO₂; regulating the flow of air to said section in response to said concentration to maintain same in a selected range, said range being 0.10 to 10% by volume when regulating in response to O₂ concentration and 6 to 14 percent by volume when regulating in response to CO₂ concentration; and continuing the preheating and flow of air until ignition of said material is effected.

5. The process of claim 4 wherein said air is passed thru said stratum into said borehole.

6. The process of claim 5 wherein said air is supplied to said section thru a series of air-injection boreholes surrounding said borehole.

7. The process of claim 4 wherein O₂ concentration is used to regulate the flow of air.

8. The process of claim 4 wherein CO₂ concentration is used to regulate the flow of air.

9. The process of claim 4 wherein the O₂ concentration is determined and same is maintained in the range of 0.10 to 5.0% by volume.

10. A process for igniting a combustible carbonaceous stratum around an ignition borehole therein comprising preheating to ignition temperature a section of stratum adjacent said borehole; during the preheating, passing air into said section at a very low flow rate in the range of 1 to 200 standard cubic feet per hour per square foot of area of said borehole thru which gas is passing, during the initial phase of said preheating, and increasing the flow rate of air as the temperature of said section increases so as to reach a very higher flow rate of air in said range when said temperature is reached, thereby igniting said

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section in a short period of time; and continuing the feeding of air to the hot stratum so as to initiate in situ combustion of said stratum.

11. The process of claim 10 including the steps of measuring the O_2 concentration in the gaseous effluent and regulating the flow rate of air so as to maintain said concentration of O_2 in the range of 0.10 to 10% by volume of said effluent. 5

12. The process of claim 10 including the steps of measuring the CO_2 concentration in the gaseous effluent and regulating the flow rate of air so as to maintain said concentration of CO_2 in the range of 6 to 14% by volume of said effluent. 10

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13. The process of claim 10 wherein air is injected thru at least one offset borehole thru said stratum to said section during preheating and thereafter to sustain combustion and initiate an inverse drive combustion.

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