March 6, 1962 M. R. TEK 3,023,807

IN SITU COMBUSTION PROCESS

Filed June 19, 1958

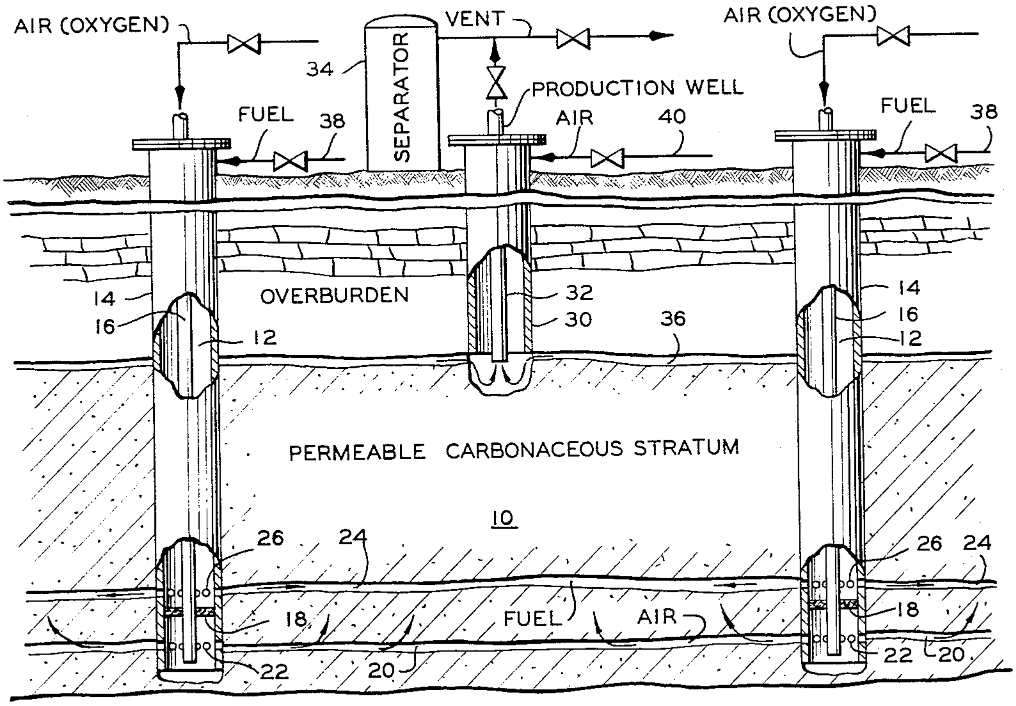

FIG. 1

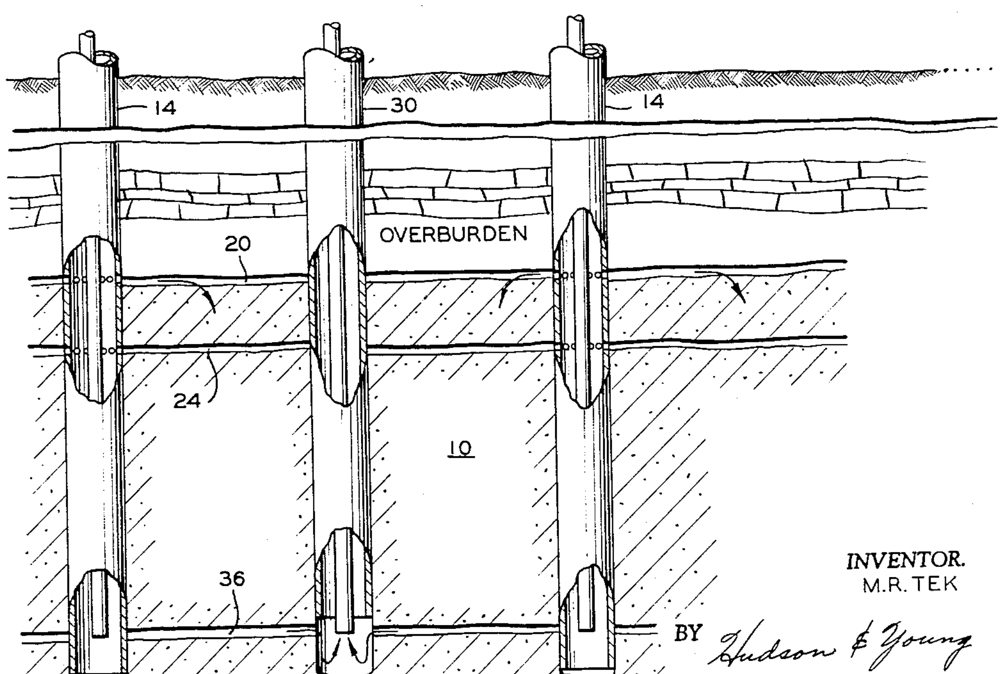

FIG. 2

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IN SITU COMBUSTION PROCESS

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This invention relates to a process for initiating in situ combustion in a carbonaceous stratum. A specific aspect of the invention is concerned with a vertical plane drive in situ combustion process in the recovery of hydrocarbons from 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 through 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 in the stratum, constitutes a direct air drive process for effecting in situ combustion and recovery of hydrocarbons from the stratum. In this type of operation the stratum frequently 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 through 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.

One of the major difficulties in producing hydrocarbons from permeable carbonaceous strata lies in the initiation of ignition of the in-place carbonaceous material. The permeability characteristics, pore size distribution, and the extremely high kinematic viscosities encountered in usual tar sand hydrocarbons make it extremely difficult to initiate and maintain a spontaneous combustion front thru the tight sand matrix. The present invention is concerned with a method of establishing spontaneous combustion in a carbonaceous stratum and maintaining combustion homogeneously distributed in a selected horizontal plane of a carbonaceous stratum from which the combustion front is readily advanced either upwardly or downwardly thru the stratum,

Accordingly, it is an object of the invention to provide an improved process for initiating spontaneous combustion in a carbonaceous stratum. Another object is to provide an improved process for recovering hydrocarbons from a carbonaceous stratum by vertical plane drive in situ combustion. A further object is to provide a process for initiating combustion in an extended selected plane in a carbonaceous stratum. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises separately injecting fuel and air into a carbonaceous stratum thru closely spaced parallel fractures therein so as to form a combustible mixture of fuel and oxygen in the stratum and thereafter igniting the mixture so as to burn the same in the stratum thereby heating the stratum in the burning zone to a temperature which supports spontaneous combustion of the in-place carbonaceous material and feeding O_2 in stoichiometric excess of the fuel to the heated area so as to initiate combustion of the in-place carbonaceous material. After ignition and combustion of the stratum in a selected plane has been effected to establish a combustion front, air or other combustion-supporting O_2-containing gas, such as pure oxygen, enriched air, or diluted air is passed thru the stratum to the combustion front so as to drive the same vertically therethru either by direct or inverse injection of the O_2. The produced hydrocarbons and combustion gas are removed at a higher or lower selected plane in the stratum, preferably thru a fracture therein around a production (or injection) borehole communicating with the fracture. In this manner, produced hydrocarbons are driven thru the stratum and are recovered from the fracture or fractures and the borehole or boreholes connected therewith.

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A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is an elevation partly in section of an arrangement of apparatus and fractures in a carbonaceous stratum illustrating one embodiment of the invention and FIGURE 2 is a similar view illustrating another embodiment of the invention.

Referring to FIGURE 1, a carbonaceous stratum **10** is penetrated by injection boreholes **12** which are provided with casing **14** and tubing **16**. The lower end of each casing annulus is packed off by means of a packer **18** around tubing **16** and fracture **20** is formed in the stratum by conventional fluid fracturing thru holes **22** in casing **14**. Fracture **24** is produced at a higher level within the range of about 6 inches to 3 feet from fracture **20** in a similar manner by injection of fracturing fluid thru holes **26**. Both fractures are preferably propped open in conventional manner.

A production borehole penetrates to an upper level of stratum **10** and is provided with casing **30** and tubing **32**. Tubing **32** leads to separator means **34** which comprises conventional equipment for resolving the effluent gases from the in situ combustion process into gaseous and liquid products and off gases. The stratum **10** is fractured and propped at the lower end of casing **30** to produce fracture **36** which overlaps fractures **20** and **24**. It is to be understood that the stratum may also be fractured at the level of fracture **36** thru casing **14** of the injection wells thru perforations in the casing which are then sealed after fracturing in order to control the flow of injected and produced gases. The well pattern shown in FIGURE 1 is normally extended laterally thru the field comprising stratum **10** so that fractures **24** and **36** continue for any selected distance thru the stratum making it possible to produce from a large number of wells simultaneously or consecutively as desired.

Casing **14** is provided with connecting conduit **38** for injection of fuel or air and casing **30** is provided with air injection conduit **40**. Tubing **16** and conduits **38** may be utilized for either air or fuel injection.

FIGURE 2 shows a similar arrangement to that of FIGURE 1 but with the fuel and air injection fractures positioned at an upper level in the stratum, preferably near the top thereof, while the production well extends to a lower level or plane of the stratum represented by fracture **36**. Other apparatus is the same as in FIGURE 1.

Utilizing the arrangement shown in FIGURE 1, air is injected thru tubing **16** into fracture **20** and fuel is injected thru lines **38** and the casing annulus into fracture **24** preferably in stoichiometric proportions to the injected air. After a short period of injection, such as 15 minutes to several hours, the air and fuel are mixed in the stratum in fracture **24** and in the stratum just above this fracture. At this time a spark or flame injected thru perforations **26** into the fracture by means of a squibb, a downhole burner, or any other suitable means (not shown) is utilized to ignite the combustible mixture in fracture **24**. The resulting flame causes combustion to spread into stratum **10** feeding upon the combustible mixture therein, and continued fuel and air injection continue the burning process until the temperature of the stratum all along fracture **24** is raised to combustion supporting temperature of the in-place hydrocarbon material. At this time, the injection of fuel can be greatly reduced or cut off gradually or entirely so that a combustion supporting excess of O_2 contacts the heated stratum and initiates combustion of the hydrocarbons or carbonaceous material therein. In this manner a combustion front along the plane of fracture **24** is established. This combustion front is in the form of a disc or pancake surrounding the wells in which the injection is effected.

During the injection of gases thru the injection wells, tubing **32** in the production well is open so that gases are free to pass out the tubing thereby facilitating the flow of air and fuel upwardly thru the stratum.

Another method of initiating combustion in the zone around fractures **20** and **24** comprises alternating, at short intervals such as 3 to 10 minutes, injecting air and fuel into fractures **20** and **24**, respectively, while maintaining production tubing **32** closed and alternately opening fuel line **38** and tubing **16** as gas is injected thru the other of these conduits so that the injected gases pass back and forth thru the intervening stratum between fractures **20** and **24** until a combustible mixture is produced within the pores of the stratum. When this is accomplished, combustion is initiated by igniting the combustible mixture in either fracture **24** or in fracture **20**, but preferably the latter so that combustion is initiated closer to the lowermost level of the stratum. After combustion is initiated in the plane of one of the fractures in a pancake area and ignition of in-place hydrocarbon is effected, continued injection of air, with or without a minor proportion of fuel, feeds the combustion zone and drives the same upwardly thru the stratum toward fracture **36**. In this embodiment of the process, it is feasible to ignite the mixture of fuel and air by injecting these gases in hot condition so as to simultaneously heat the restricted section of stratum intermediate the fractures and when the temperature thereof reaches the range of about 500 to 700°, the ignitable mixture is automatically or spontaneously ignited and combustion commences.

After initiating combustion in a pancake area adjacent the injection fractures at the selected level, the combustion front thus established may also be moved vertically thru the stratum by injecting air thru the well or borehole leading to the remote fracture and recovering production in the boreholes utilized as injection boreholes during the initiation of combustion. In following this technique in the arrangement shown in FIGURE 1, air is injected thru line **40** into the casing annulus from which it passes into fracture **36** and then thru the permeable stratum **10** to the fire front with combustion gases and production passing to fracture **24** and/or fracture **20** from which the produced gases are recovered thru casing **14** and/or tubing **16** in conventional manner. The first burn thru by inverse air injection leaves a carbonaceous residue in the stratum which can then be produced by a second burn thru by direct drive. In this manner when the combustion front reaches fracture **36** the second burning phase by direct drive is initiated by continuing the injection of air into fracture **36** whereupon the fire front reverses and moves back thru the stratum after a short burning period adjacent the fracture.

Operation with the arrangement shown in FIGURE 2 is very similar to that described relative to FIGURE 1, the principal difference being in the location of the closely spaced fractures **20** and **24** in a section of the stratum above fracture **36**. The same injection procedures are applicable to both arrangements.

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 hydrocarbon-bearing stratum comprising horizontally fracturing said stratum at two closely spaced levels around an injection borehole therein; separately injecting a fuel gas into the fracture at one level and oxygen into the fracture at the other level; forcing the fuel gas and oxygen toward a remote third level in said stratum so as to form a combustible mixture of these gases in the fracture nearest said third level and in the adjacent stratum; igniting the resulting mixture in the fracture nearest said third level; continuing the injection of said gases and the combustion thereof in said stratum so as to heat a substantial area thereof to combustion supporting temperature; terminating the injection of fuel gas; and continuing the injection of oxygen so as to burn in-place hydrocarbons and establish in situ combustion in said stratum.

2. The process of claim 1 including the steps of fracturing said stratum at said remote level around a production borehole therein so that the fractures around said injection borehole and said production borehole overlap; and withdrawing hydrocarbons driven from said stratum by said combustion thru the remote fractures.

3. The process of claim 2 wherein the fractures around said injection borehole are at a lower level of said stratum.

4. The process of claim 2 wherein the fractures around said injection borehole are at an upper level of said stratum.

5. The process of claim 1 further comprising periodically varying the rate of flow of one of the injected gases relative to the other to increase mixing of said gases in said stratum.

6. The process of claim 5 wherein approximately stoichiometric portions of said gases are injected for a portion of the injection period.

7. The process of claim 1 including the steps of fracturing said stratum at said remote level around an offset production borehole therein so that the fractures around said injection borehole and said production borehole overlap, the fractures at said remote level avoid direct communication with said injection borehole and the fractures at said closely spaced levels avoiding direct communication with said production borehole; after in situ combustion has been established, injecting air at said remote level and discontinuing injection of gases thru said injection borehole so as to force air to the in situ combustion level and move the combustion zone toward said remote level inversely to the flow of air; and recovering produced hydrocarbon thru said injection borehole.

8. A process for initiating in situ combustion in a hydrocarbon-bearing stratum comprising horizontally fracturing said stratum at two closely spaced levels around an injection borehole therein; separately injecting a fuel gas into the fracture at one of said levels and oxygen into the other fracture thru said injection borehole; forcing the fuel gas and oxygen toward a remote third level in said stratum so as to form a combustible mixture of these gases in the fracture nearest said third level and in the area adjacent said fractures; igniting the resulting mixture in said stratum; continuing the injection of fuel gas and oxygen so as to heat up a substantial area of said stratum to combustion supporting temperature; reducing the proportion of fuel gas injected so as to provide a sub-

stantial stoichiometric excess of oxygen, thereby igniting the in-place hydrocarbons and establishing in situ combustion in said stratum; and recovering hydrocarbons thus produced thru an offset production borehole communicating with said stratum.

9. The process of claim 8 wherein produced hydrocarbons are recovered thru a fracture at said third level communicating with said production borehole.

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