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PROCESS AND APPARATUS FOR IN SITU COMBUSTION

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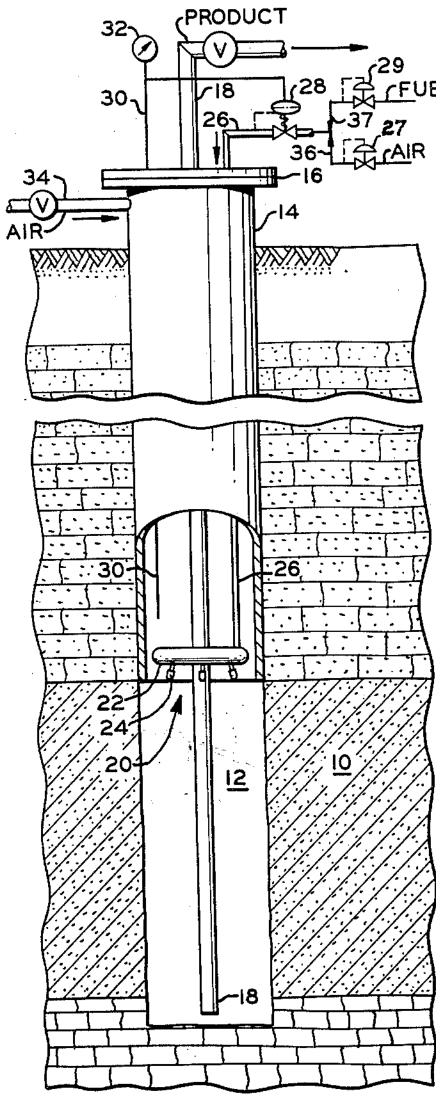

FIG. 1

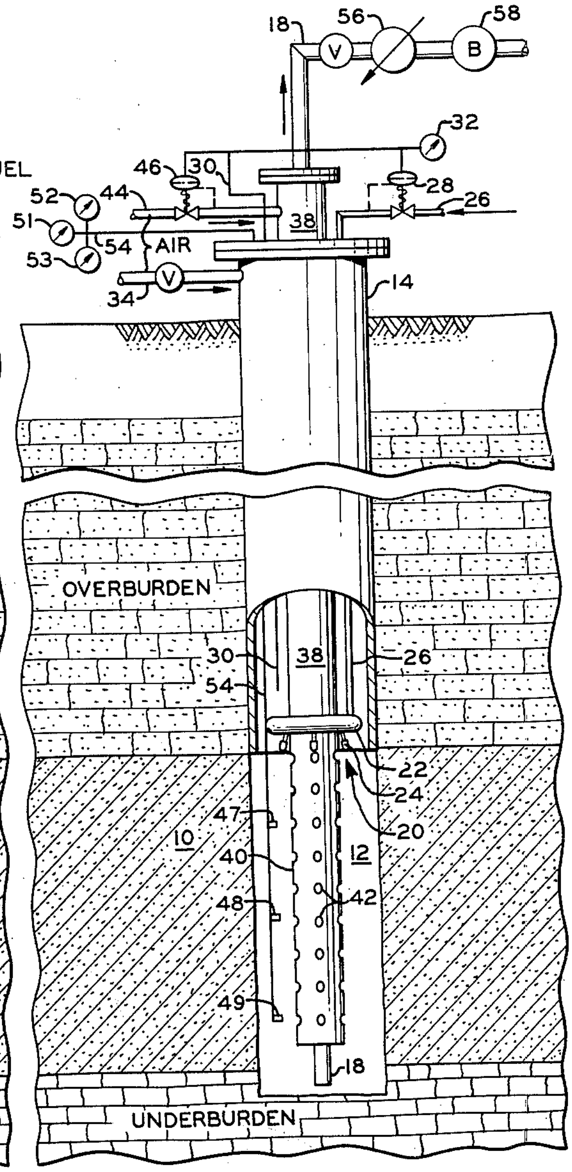

FIG. 2

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PROCESS AND APPARATUS FOR IN SITU COMBUSTION

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This invention relates to a process and apparatus for igniting a carbonaceous stratum by in situ combustion.

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 thruogh 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 is a direct air drive process for effecting in situ cmbustion 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 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 through 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. A known method of ignition comprises heating the stratum around a borehole by means of a downhole heater of the gas-fired type. When heating the stratum in this manner it has been found that conventional heaters have heated the stratum only a portion of its thickness or extent within the borehole so that ignition was effected at a restricted level in the stratum and not throughout its entire vertical extent, which is necessary if a combustion front extending from the top to the bottom of the stratum is to be moved through the stratum to other boreholes therein.

Accordingly it is an object of the invention to provide a downhole heater arrangement which heats a stratum around the wall of a borehole therein completely across the vertical extent of the stratum. Another object is to provide an improved process for heating and igniting a carbonaceous stratum around a borehole therein which ignites the entire section of the exposed stratum. A further object of the invention is to provide a process and arrangement of apparatus which permits control of the vertical extent of the flame or actual combustion zone from a downhole heater. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

The apparatus of the invention comprises a burner arrangement in a borehole in a carbonaceous stratum wherein the burner is positioned adjacent the top of the stratum and an exhaust conduit is positioned in the borehole with its inlet end adjacent the bottom of the stratum whereby flame, by proper regulation of the fuel and air pressure, can be extended so as to contact the entire vertical surface of the stratum exposed within the borehole.

The broad aspect of the process of the invention comprises injecting fuel gas downwardly along the wall of a borehole in a carbonaceous stratum in contact therewith from the upper to the lower level thereof; mixing an O_2-containing gas with the fuel gas thus injected; burning the resulting admixture in contact with the stratum so as to heat the same from top to bottom within the borehole; withdrawing combustion gases from the borehole at the lower level of the stratum; continuing the burning step until the stratum adjacent the borehole is heated to ignition temperature; and contacting the thus heated stratum wih O_2 so as to ignite the carbonaceous material therein. The flow of fuel gas and air to the combustion zone is controlled in accordance with the gas pressure in the borehole and the flow rates of these gases are also regulated so as to extend the flame or combustion zone along the entire surface of the stratum exposed to the borehole.

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 one embodiment of a downhole heater arrangement in accordance with the invention; and FIGURE 2 is a similar elevation showing another embodiment of the invention.

Referring to FIGURE 1, a stratum **10** is penetrated by a borehole **12** which is provided with a casing **14** extending to the approximate level of the top of the stratum. Extending through well head **16** is tubing **18** which functions as an exhaust conduit during the ignition process and as production tubing during the recovery of hydrocarbons by in situ combustion when borehole **12** is utilized as a production borehole (utilizing inverse air injection technique). A burner **20**, comprising an annular burner body **22** and a ring of jets **24** extending downwardly therefrom, is positioned on tubing **18** at the approximate level of the top of stratum **10**. Jets **24** should be spaced sufficiently close to provide a complete annulus of fuel gas adjacent the wall of the borehole. These jets or nozzles are preferably directed radially outwardly a few degrees from the axis of the borehole so as to effect better flame contact with the stratum during the burning process.

A burner **20** is fed by a supply line **26** in which is positioned a differential pressure regulator **28** for control of the flow rate through this line. Line **26** is supplied from air line **36** and fuel line **37**, wherein flow is controlled by regulators **27** and **29**, respectively. Differential pressure regulator **28** and flow regulators **27** and **29** are conventional commercially available instruments. The amount of air introduced thru line **36** should be less than theoretical and preferably below 60% thereof. A gas pressure line **30** extends into borehole **12** through the well head and connects with motor valve **28** and is arranged to increase and decrease the flow rate of fuel as pressure in the borehole increases and decreases, respectively. Pressure gauge **32** in line **30** indicates the pressure within the borehole. Air line **34** connects with the well annulus via casing **14** to supply combustion air for injected fuel and, also air for the in situ combustion process when direct air injection is utilized in ignition of the stratum or in the ensuing in situ combustion process.

Referring to FIGURE 2 corresponding numerals represent corresponding elements to those of FIGURE 1. The arrangement of apparatus in FIGURE 2 is similar to that in FIGURE 1, but includes a conduit **38** concentric with tubing **18** and extending substantially to the bottom of the stratum. The lower section **40** of conduit **38** below burner **20** is provided with secondary air injection ports or holes 42 spaced longitudinally and circumferentially along the wall thereof. Air supply line 44 connects with the annulus between tubing 18 and conduit 38 for supply of secondary air to the combustion process through ports 42. Gas-pressure sensing line 30 is also connected with differential pressure regulator 46 in air supply line 44, as well as with differential pressure regulator 28 in line 26. Fuel or a mixture of fuel and air is fed to line 26 substantially as shown in FIGURE 1.

A series of thermocouples 47, 48, and 49 positioned in borehole 12 along stratum 10 are separately connected with indicators 51, 52, and 53, respectively, through separate leads in conduit 54.

A condenser 56 and an exhaust pump 58 are provided in tubing 18, particularly for use in recovery of hydrocarbons during in situ combustion by inverse air injection, but they may also be used during the ignition process.

In operation in accordance with an embodiment of the process illustrated in FIG. 1, fuel is injected through line 26 to burner 20 with or without primary air injected through line 36 and the air is also injected through line 34 into the annulus between tubing 18 and casing 14 in stoichiometric excess of the fuel requirements. The rates of flow of fuel and air are regulated so as to provide a flame or combustion zone along the entire surface of borehole 12 within stratum 10 so as to heat the entire cross section of stratum exposed by the borehole. As pressure in the borehole increases and decreases the same is sensed through line 30 which varies the amount of opening in valve 28. Air admitted through line 34 is regulated according to the pressure indicated on gauge 32. When introducing primary air through line 36 the amount of air so introduced can be regulated in accordance with the amount of fuel injection through line 26. Combustion gases are exhausted through tubing 18 during the heating step.

Heating is continued until the ignition temperature of the carbonaceous stratum is reached and this temperature usually lies in the range of about 450 to 700° F. When the ignition temperature is stratum 10, or some temperature in the aforesaid range is reached, it is necessary to contact the hot stream with excess O_2 and this may be supplied either through line 34 by increasing the flow therethrough or by cutting down on the rate of fuel injection or by both expedients. It is also feasible to initiate injection of air or other O_2-containing gas through stratum 10 from one or more boreholes therein spaced a short distance from ignition borehole 12. In this manner ignition of the carbonaceous material is stratum 10 adjacent borehole 12 is effected and, as a substantial combustion zone within the stratum is established, injection of fuel through line 26 is terminated and the burner may be withdrawn from the borehole.

Operation of the process of the invention utilizing the arrangement of apparatus of FIGURE 2 is similar to operation with the apparatus of FIGURE 1 in many respects; however, secondary air is fed to the combustion area via line 44, conduit 38 and holes or ports 42 in section 40. By adjusting the fuel to air ratio to provide at least the stoichiometric amount of air for complete combustion and by providing sufficient fuel to fire the complete combustion area from the top of the stratum 10 to the bottom thereof, the entire carbonaceous stratum surrounding the borehole is directly heated with flame thereby contributing to high efficiency and rapid heating of the section of stratum immediately surrounding the borehole to the ignition temperature of the carbonaceous material. Adjustment of the flow rate of fuel is facilitated by thermocouples 47, 48, and 49, which sense the temperature at different levels in the borehole within the stratum and indicate whether the flame area or the combustion zone is reaching the lowest level of the stratum. When the optimum fuel flow rate is determined and regulator 28 is properly regulated for this flow with

a given gas pressure within the borehole, control of the regulator 28 is responsive to changes in gas pressure within the borehole. Gas pressure within the borehole also acts through line 30 to vary the flow of air through line 44 by regulation of regulator 46. A portion of the air requirements for the complete combustion of the fuel injected through line 26 is injected through line 34 whereby air reaches burner 20 through the annulus between conduit 38 and the well casing. Where desired a portion of the primary air may be injected through line 26. Using the arrangement of either figure, it is desirable to initiate slow air flow thru stratum 10 to borehole 12 at least during the later stages of heating.

After the section of stratum 10 around borehole 12 has reached the ignition temperature of the carbonaceous material therein, the ignition thereof is readily accomplished in the same manner as indicated in connection with FIGURE 1. It is preferred to utilize inverse injection of air through surrounding or adjacent boreholes in moving the established combustion zone through the stratum radially outwardly from borehole 12. When operating in this manner tubing 18 serves as production tubing, water vapor being condensed in condenser 56 and the remaining gaseous effluent being passed by blower or pump 58 to further processing in conventional manner.

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. Apparatus for use in igniting a carbonaceous stratum comprising in combination an annular burner tube positioned on a well tubing in a borehole adjacent an upper section of said stratum, said burner being provided with a ring of depending jets directed downwardly along the unlined borehole wall and said tubing extending to a remote lower level of said stratum and serving as an exhaust conduit for said burner to provide an annular combustion chamber between said burner tube and the lower end of said exhaust conduit enclosed directly by the unlined wall of said borehole, whereby flame and hot combustion gases directly contact said unlined wall along its extent between said burner tube and the lower end of said tubing; a fuel line connected with said burner tube; conduit means extending from ground level to said jets for supplying and mixing O_2-containing gas with said fuel at said jets; a valve in said fuel line; pressure sensitive means at the locus of said burner in control of said valve for regulating the flow through said valve as gas pressure adjacent said burner varies.

2. The apparatus of claim 1 wherein said tubing extends to the bottom of said stratum and is adapted to withdraw combustion products and fluid hydrocarbons from said borehole.

3. The apparatus of claim 2 wherein said jets are also directed outwardly from said tubing.

4. Apparatus for use in igniting a carbonaceous stratum along an extended length of borehole therein comprising in combination, an unenclosed burner positioned on a well tubing in a borehole adjacent an upper section of bare stratum, said burner comprising an annular burner body encircling said tubing having a ring of depending jets directed downwardly along said stratum, said tubing extending to a lower level of said stratum and being provide with secondary air ports below said burner body; an air inlet in the upper end of said tubing for secondary air; a fuel line connecting said body with a source of fuel; conduit means extending from ground level to said jets for supplying and mixing primary air with said fuel at said jets; an an exhaust conduit within said tubing extending from a level adjacent the lower end of said tubing to the surface.

5. The apparatus of claim 4 including a valve in said fuel line and pressure sensing means in said borehole adjacent said burner in control of said valve.

6. The apparatus of claim 4 wherein said means comprises an air line communicating with the annulus between said tubing and the wall of said borehole for supplying air to said annulus.

7. A process for igniting carbonaceous material in a stratum around a well bore therethrough which comprises injecting fuel gas downwardly along the bare wall of an elongated section of said borehole in contact with said stratum from an upper to a lower level thereof; admixing O_2-containing gas with said fuel gas and burning the resulting admixture in direct contact with the bare wall of said stratum so as to heat said stratum throughout said section of said borehole; withdrawing combustion gases from said borehole at a lower level of said stratum axially thru said borehole; continuing the burning step until said section of stratum is heated to ignition temperature; and contacting the resulting hot stratum with O_2 so as to ignite same.

8. The process of claim 7 wherein the O_2-containing gas is air, and including the steps of mixing primary air with said fuel gas at the level of injection and injecting secondary air into said fuel gas radially from the axis of said borehole along the length of said borehole within said stratum.

9. The process of claim 8 including the steps of sensing the temperature at different levels intermediate said upper and lower levels and regulating the flow rates of air and fuel gas in response thereto so as to assure combustion at all of said levels; thereafter sensing the gas pressure adjacent said stratum in said borehole and increasing and decreasing flow rate of fuel as said pressure increases and decreases to maintain optimum combustion conditions.

10. The process of claim 9 including increasing and decreasing the flow rate of secondary air in response to increases and decreases in said gas pressure.

11. The process of claim 7 wherein O_2-containing gas is passed through said stratum into said borehole to ignite said carbonaceous material.

12. A downhole burner for heating an elongated section of borehole wall comprising a burner ring attached to a well tubing and positioned horizontally at the upper end of the section to be heated; an exhaust conduit extending from ground level axially thru said ring and perpendicular thereto to provide an exhaust outlet for combustion gases at the opposite end of the section to be heated, there being an annular combustion chamber extending from said ring to said outlet and bounded directly by the adjcent borehole wall; a ring of jets on the side of said ring facing said exhaust outlet, being adapted to direct flame and hot gases along and in direct contact with said borehole wall toward said exhaust outlet; and conduit means communicating with said jets for feeding fuel gas and free-O_2-containing gas thereto.

13. A down hole burner for heating an elongated section of borehole wall comprising a burner ring provided with downwardly directed ports and supported on a well conduit adjacent the upper end of the section to be heated, said conduit extending from the well head to a locus adjacent the lower end of said section to form a combustion chamber between said ring and the lower end of said conduit bounded by the bare wall of said borehole; ports below said ring spaced longitudinally and circumferentially along said conduit leading into said combustion chamber for passing secondary air radially outwardly into said chamber; an inner concentric exhaust tubing extending from the well head to a locus subjacent the lower end of said conduit and providing an exhaust outlet at its lower end; air inlet means in said conduit for feeding air into the annulus between said tubing and said conduit; conduit means leading from the well head to said burner ring for supplying fuel thereto; and means for supplying primary air to the area adjacent said burner ring.

14. The burner of claim 13 including downwardly and radially outwardly directed jets in the ports of said burner ring, same being spaced along the lower side of said burner ring and communicating therewith.

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