

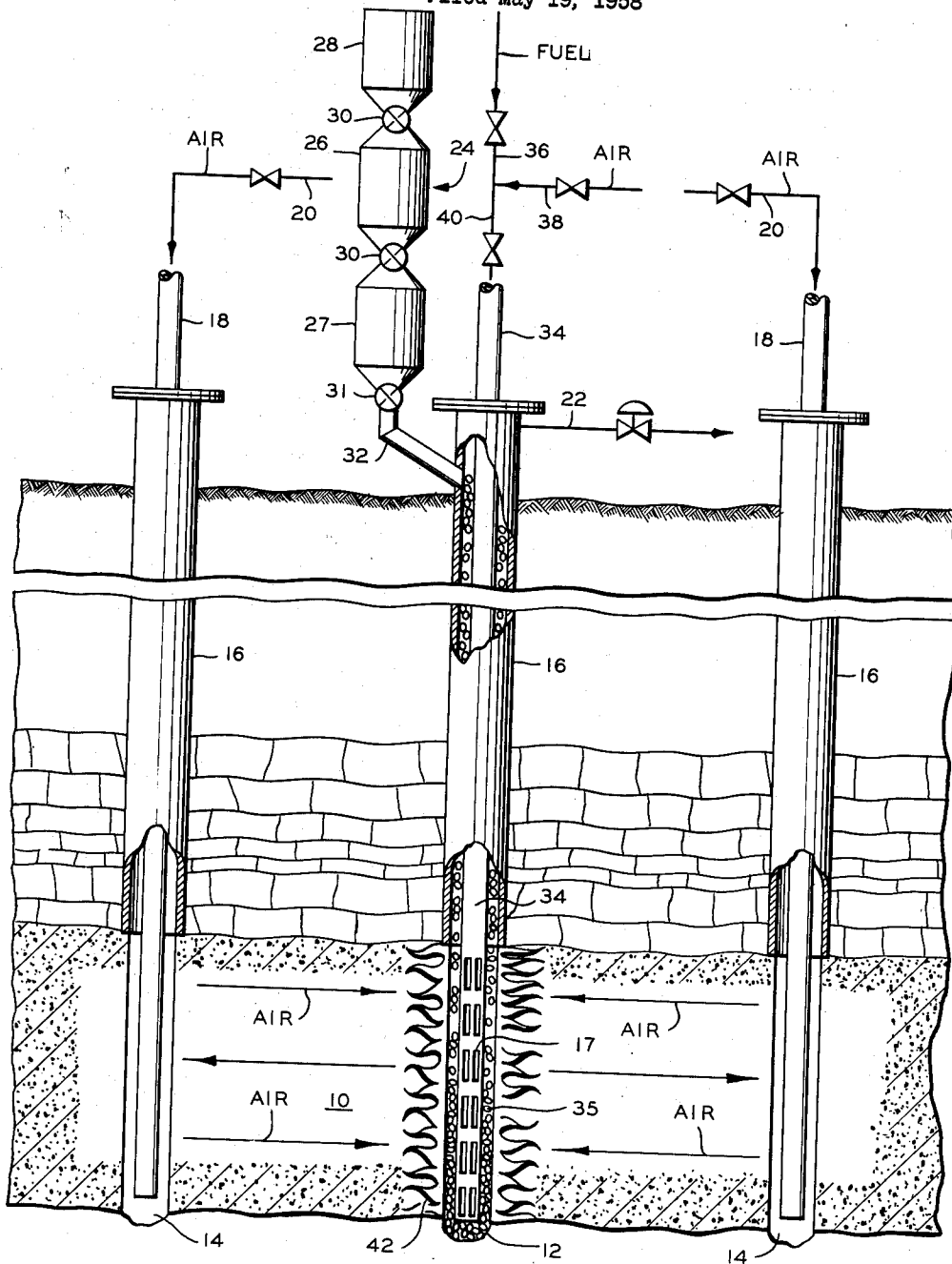
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PROCESS FOR INITIATION OF IN SITU COMBUSTION

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PROCESS FOR INITIATION OF IN SITU COMBUSTION

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This invention relates to a process for initiating in situ combustion in a permeable 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, in the inverse drive process, 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.

Whether using a direct air drive or an inverse air injection in situ combustion process, it is first necessary to ignite the carbonaceous stratum around a borehole therein before a combustion front can be caused to move thru the stratum. It has been found difficult to establish a self-sustaining combustion zone in most carbonaceous strata. One method heretofore utilized comprises packing a mass of particulate charcoal into a borehole within the stratum to be ignited and, after igniting the charcoal, injecting air into the mass of charcoal so as to heat the wall of the borehole to ignition temperature. In this technique, combustion gas is either passed thru the stratum to surrounding boreholes or it is vented thru the ignition borehole. In either case, the borehole wall is subjected to temperature as high as 2500° F. which causes sintering of the siliceous formation with loss of permeability, thereby increasing the problem of recovery. If combustion gas is vented thru the stratum to other boreholes, the stratum is contaminated with combustion products and with ashes from the charcoal with probability of plugging by liquid hydrocarbons, ashes, etc.

Another problem in initiating in situ combustion lies in the difficult in supplying air (O₂) to the hot section of stratum around the ignition borehole when the temperature thereof is above ignition temperature. If direct air drive is utilized while the charcoal is still burning, it is difficult to supply O₂ in high enough concentration, utilizing air, to readily ignite the carbonaceous stratum. When air is fed thru the stratum from surrounding boreholes, the fluids in the stratum such as gaseous hydrocarbons and water are driven into the ignition borehole and substantially cool the stratum to be ignited before air arrives.

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The invention is directed to a process for igniting a carbonaceous stratum and initiating in situ combustion therein which avoids some of the problems of the prior art, as enumerated above.

It is, accordingly, an object of the invention to provide an improved process for igniting a carbonaceous stratum and initiating in situ combustion therein. Another object of the invention is to avoid drastically cooling the heated area around an ignition borehole during ignition of a carbonaceous stratum. A further object is to avoid contamination of the section of carbonaceous stratum around an ignition borehole during initiation of in situ combustion therein. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises pressurizing a carbonaceous stratum around an ignition borehole therein with air, thereafter heating the wall of the borehole at least to ignition temperature of the carbonaceous material therein and while at this temperature releasing gas from said borehole so as to reduce the pressure therein and cause O₂ to flow from the stratum into the hot borehole wall, thereby initiating combustion of in-place carbonaceous material. Although any effective method of heating the wall of the borehole may be utilized, a preferred method comprises burning a mass of particulate charcoal in the borehole within the stratum. Air for combustion of the charcoal is supplied, at least in part, by injection thru a conduit or well tubing directly into the mass of charcoal. It is also desirable to allow a slow flow of air from the pressurized zone into the borehole, particularly during the later stages of heating, so as to avoid overheating of the borehole wall adjacent hot spots in the charcoal mass and to flush hydrocarbons from the hot section of stratum adjacent the borehole which are fluidized by the heating process. This feature of the process also assures a fresh supply of oxygen in the hot area at the time when the ignition temperature is reached.

After ignition of the carbonaceous material has been effected, the resulting combustion zone readily moves thru the stratum countercurrently to the flow of air toward the injection borehole or boreholes to establish an inverse in situ combustion process by passing air thru said stratum at a rate of at least about 20 standard cubic feet per square foot of combustion front per hour. During this process, produced hydrocarbons are recovered thru the ignition borehole by conventional methods. In strata of suitable characteristics for direct air drive without plugging of the stratum, injection of air thru the ignition borehole may be effected so as to drive the combustion zone to a ring of surrounding production wells.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing which is an elevation in partial section showing an arrangement of apparatus in boreholes thru a carbonaceous stratum for effecting the process of the invention.

Referring to the drawing, a permeable carbonaceous stratum 10 is penetrated by an ignition borehole 12 and injection boreholes 14. Each of the boreholes is provided with a casing 16 extending to the upper level of the stratum. Air injection tubing 18 in boreholes 14 extends out thru the well head and connects with an air line 20. An exhaust or production line 22 connects with casing 16 of borehole 12 and a charcoal feeder system 24, including a pair of pressure chambers 26 and 27 and a hopper 28 connected by star valves 30 deliver charcoal thru a third star valve 31 and conduit 32 under pressure into casing 16. Well tubing 34 passes thru the well head to an area within borehole 12 intermediate

the top and bottom of stratum 10. A fuel line 36 and an air line 38 connect with tubing 34 thru line 40. Numeral 42 designates a fire front in stratum 10 ignited around ignition borehole 12.

Borehole 12 illustrates a central ignition borehole surrounded by a ring of injection boreholes 14. It may also represent an ignition borehole in a line of in-line ignition boreholes flanked on each side by a parallel line of in-line boreholes 14. In either type of borehole spacing and recovery process, a fire front is initiated around borehole or boreholes 12, which is then driven outwardly toward boreholes 14 by injection of air thru boreholes 14 where an inverse air injection process is utilized, but thru borehole or boreholes 12 when utilizing a direct drive process.

In operation of the process, assuming ignition borehole 12 is a central borehole surrounded by a ring of injection boreholes, air is injected into the stratum intermediate borehole 12 and boreholes 14 either thru the central borehole or thru the ring of boreholes so as to flush out fluid material from the stratum which is then recovered thru the ring of boreholes or thru the central borehole, depending upon the direction of injection. This flushing procedure removes fluid hydrocarbons and water from the stratum which are displaced by the injected air. This procedure is followed until the effluent gas is mostly air. It is preferred to inject air thru the injection boreholes and recover displaced fluids thru borehole 12 by means of tubing 34 (with an imperforate bottom section) which can be lowered to the bottom of the hole so as to take off liquids as well as gases driven from the stratum. After air passes freely from the well tubing 34 or thru conduit 22, the perforate section is placed on tubing 34, charcoal is packed around same, borehole 12 is shut in, and the stratum is pressurized by injection of air thru lines 18 until the pressure in the injection boreholes reaches a value of at least about 50 p.s.i.g. and may be up to the capacity of the compressor or the fracturing or lifting pressure of the stratum. At this time a fire is initiated in charcoal mass 35 by means of a fusee, squib, electric heater, or other suitable means, such as dropping red hot charcoal on the mass of charcoal within stratum 10. Air is fed into the burning charcoal thru conduit 34 and gas is vented thru line 22, or if desired, the air is fed thru line 22 and gas is vented to tubing 34. By injecting a mixture of fuel gas and air from lines 36 and 38, respectively, thru slots 17 in tubing 34, the entire mass of charcoal may be ignited and burned simultaneously after original ignition so as to heat the entire cross section of stratum around borehole 12. If this method is utilized, fresh charcoal is continuously or intermittently introduced thru system 24 so as to replenish the charcoal as it is consumed and maintain the bed or mass of charcoal up to the level of the top of stratum 10.

During the heating process, the temperature of the borehole wall is sensed by thermocouples (not shown) and as the temperature thereof approaches ignition temperature, such as a temperature in the range of about 450 to 700° F., pressure in borehole 12, which up to this time has been maintained in the range of about 40 to 2000 p.s.i.g. or higher (if the stratum is deep enough to withstand such pressures without fracturing or lifting) is reduced gradually so as to allow air to flow from pressurized stratum 10 thru the hot borehole wall into borehole 12. As the temperature of the surrounding stratum reaches the ignition temperature under these conditions of operation, the ignition of in-place hydrocarbons or carbonaceous material is effected. When this occurs, air is injected thru tubing 18 and/or the pressure within borehole 12 may also be reduced to increase the flow of air. The air flow rate should be at least about 20 standard cubic feet per square foot of fire front per hour to maintain inverse movement of the front.

While it is feasible to initiate combustion in the stratum around borehole 12, after it has reached ignition tempera-

ture, by merely reducing the pressure within borehole 12 as by increasing the vent rate thru line 22, it is desirable to also begin the injection of air thru line 18 while initiating combustion around borehole 12 as this begins movement of air thru the stratum from boreholes 14 to support the inverse air injection process whereby the resulting combustion zone around borehole 12 is caused to move laterally outwardly to boreholes 14. Upon arriving at boreholes 14, the combustion front can be driven back thru stratum 10, feeding upon the unburned carbonaceous residue left by the first burning wave, by injecting air thru tubing 18 after the front arrives at the wall of boreholes 14.

Another embodiment of the invention comprises allowing the pressure in borehole 12 to gradually and slowly decrease during the burning of charcoal mass 35 particularly when the wall of the borehole approaches ignition temperature so as to assure a fresh supply of oxygen in the heated area and to prevent overheating in localized hot spots adjacent the charcoal bed.

The invention is also useful in re-igniting a stratum in which a combustion front has been moved thru a stratum away from a borehole and has died out for any reason. By heating the stratum around a borehole surrounded by burned out stratum to ignition temperature in the manner described and injecting a combustible premix of air and fuel thru the unburned stratum to the hot borehole, a hot zone moves out into the stratum countercurrently to the flow of premix and reaches the unburned zone. When this occurs, excess O₂ in the premix re-ignites the carbonaceous deposit and re-establishes in situ combustion. The concentration of fuel in the premix may then be reduced and combustion will continue.

While the burning of charcoal has been described thus far as the means of heating the ignition borehole, it is also feasible to utilize other solid fuel such as coal, coke, or porous ceramic material saturated with a heavy hydrocarbon liquid fuel. One such fuel comprises a mixture of diesel fuel and asphalt. Porous alumina, fire brick in particulate form, or porous ceramic pebbles soaked with such fuel form an effective fuel mass in the ignition borehole.

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 permeable carbonaceous stratum penetrated by an injection borehole and an ignition borehole, which comprises flowing air thru said stratum between said boreholes so as to flush fluids into and produce same from one of said boreholes until air is present in the production effluent; thereafter, shutting in one of said boreholes and building up air pressure in said stratum by injecting air thereinto; extending a tubing string into said ignition borehole having a perforate lower end section coextensive with said stratum; packing particulate mass of solids containing fuel around the tubing string including said perforate section and extending to the top of said stratum; injecting a combustible mixture of hydrocarbon and air into said mass along its entire length by means of said perforate section and burning same therein to heat said fuel to combustion-supporting temperature; releasing gas from said ignition borehole so as to cause air to flow into said mass and burn said fuel; continuing the burning of said fuel by injecting air thru said injection borehole and thru said stratum into said ignition borehole, whereby the adjacent stratum is heated to ignition temperature and is ignited.

2. The process of claim 1 wherein a mass of charcoal is packed around said tubing string.

3. The process of claim 2 wherein charcoal is dropped onto said mass as the top level of said mass of charcoal recedes as burning continues so as to maintain the top

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level of the burning charcoal at least as high as the top of said stratum.

4. A process for initiating in situ combustion in a permeable carbonaceous stratum penetrated by an injection borehole and an ignition borehole, which comprises flowing air thru said stratum from said injection borehole to said ignition borehole so as to flush fluids into and produce same from said ignition borehole until air is present in the production effluent; extending a tubing string into said ignition borehole having a perforate lower end section coextensive with said stratum; packing particulate mass of solids containing fuel around said perforate section extending to the top of said stratum; closing in said ignition borehole and injecting air into said stratum thru said injection borehole so as to build up pressure in said stratum; thereafter injecting a combustible mixture of hydrocarbon and air into said mass along its entire length by means of said perforate section and burning same therein to heat said fuel to combustion-

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supporting temperature; releasing gas from said ignition borehole so as to cause air to flow from the pressurized stratum into said mass and burn said fuel; continuing the burning of said fuel by injecting air thru said injection borehole and thru said stratum into said ignition borehole, whereby the adjacent stratum is heated to ignition temperature and is ignited.

5. The process of claim 4 wherein said mass comprises charcoal and charcoal is added to the top of said mass as burning progresses so as to heat and ignite the entire cross section of said stratum.

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