

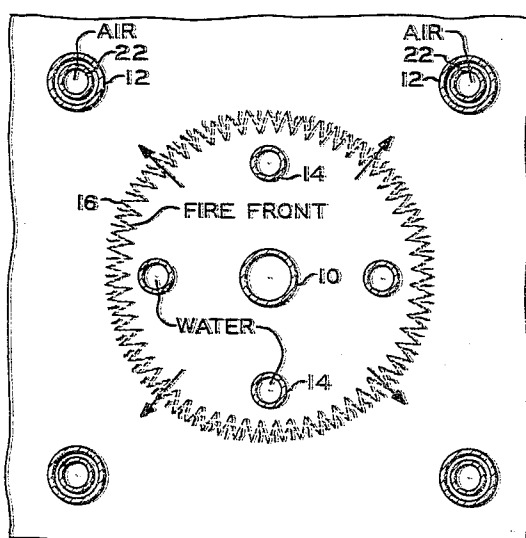
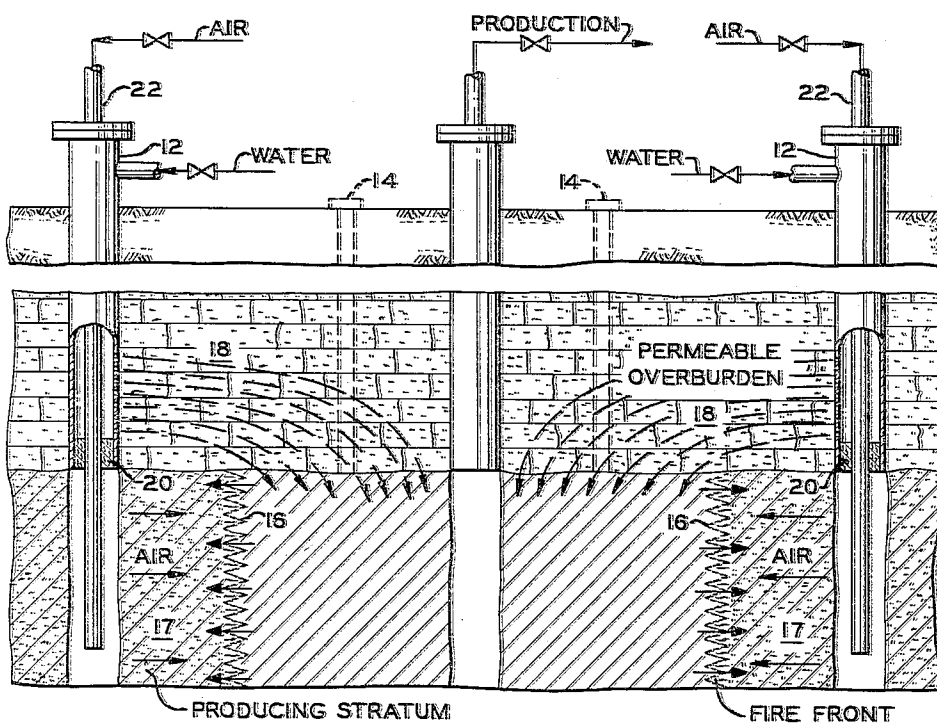
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RECOVERY OF HYDROCARBONS BY IN SITU COMBUSTION

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RECOVERY OF HYDROCARBONS BY IN SITU COMBUSTION

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This invention relates to a process for producing hydrocarbons from 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 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 either type of in situ combustion substantial injection pressure is required to force the combustion air and other gases thru the formation, although considerably higher pressure is usually required in a direct drive process due to the highly viscous material just in front of the combustion zone. Unless air is fed to the combustion zone at adequate rates to maintain the stratum well above combustion supporting temperature, the combustion dies out for lack of adequate air supply. Heretofore as the flow rate of air to the combustion zone has decreased, the injection pressure has been increased so as to maintain adequate injection air flow rates. This invention is concerned with a method of decreasing the injection pressures required to sustain adequate rates of combustion and movement of the combustion front.

Accordingly, it is an object of the invention to provide an improvement in the recovery of hydrocarbons from a carbonaceous stratum by in situ combustion utilizing inverse air injection. Another object is to provide a process which lowers the injection pressure required in the recovery of hydrocarbons by inverse air injection in situ combustion. It is also an object of the invention to provide an inverse air injection in situ combustion process which lowers the pressure and flow resistance of the fluids in the stratum behind the combustion front. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

The broadest aspect of the process of the invention comprises injecting water into the hot stratum behind the combustion front in an inverse air injection process thereby reducing the pressure and flow resistance of the gases flowing thru the stratum intermediate the combustion front and the production well or wells (where more than

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one is utilized to withdraw combustion gas and produced hydrocarbons).

By lowering the temperature of the gases downstream of the combustion front, a greater pressure drop thru the formation is effected so that greater flow rates with a given injection pressure are obtained or the injection pressure can be reduced with a given flow rate of injected air.

The amount of water injected into the hot formation behind the combustion front in an inverse air injection process is regulated so as to maintain a temperature in the stratum above the dew point of water. Of course, substantially all of the injected water that reaches the hot area of the stratum intermediate the combustion front and the production borehole is vaporized and remains in vapor form as it passes out of the stratum into the production borehole when operating in accordance with the process of the invention.

A more complete understanding of the invention may be had by referring to the schematic drawing of which FIGURE 1 is a plan view showing a preferred arrangement of wells or boreholes in effecting one embodiment of the invention, while FIGURE 2 is an elevation showing an arrangement of wells and apparatus suitable for effecting another embodiment of the invention. Referring to FIGURE 1, a 5-spot well pattern is shown including production well 10 and injection wells 12. Boreholes 14 are utilized for injecting water into the formation behind combustion front 16. Obviously other well patterns may be utilized. In one type of operation, in situ combustion utilizing inverse air injection is initiated in a string of boreholes or production wells in a straight line thru a field and a line of boreholes on each side of the line of production boreholes is utilized for the injection of air to move the combustion zone thru the stratum in both directions from the production wells toward the injection wells.

FIGURE 2 shows a pair of air injection wells 12 on either side of production well 10, all penetrating producing stratum 17 which lies under gas permeable overburden 18. Each of the injection wells 12 is packed off at the upper level of the producing stratum by packers 20 between the well casing and tubing 22. By this arrangement the air injected thru tubing 22 is available to the producing stratum, only, and water injected thru the annulus at the well head is available to the permeable stratum above the producing stratum but not to the producing stratum itself. The position of water injection holes 14 is shown in dotted lines in the event the embodiment of the invention shown in FIGURE 1 is utilized. The fire front 16 is shown at an intermediate stage of the process when the same has moved out a substantial distance from production well 10. Recovery equipment conventionally utilized in production well 10 is not shown.

When operating in accordance with the embodiment shown in FIGURE 1, combustion is initiated in the carbonaceous stratum adjacent borehole 10 by conventional and suitable means such as a downhole heater, injection of hot oxygen-containing gas, or by pyrotechnics, and inverse air or other oxygen-containing combustion-supporting gas is injected thru boreholes 12 and the same is forced thru the stratum to the hot area around well 10. It is also feasible to utilize boreholes 14 as air injection boreholes to facilitate the ignition of the carbonaceous stratum intermediate the boreholes 14 and 10. After the combustion front has moved a substantial distance outwardly from borehole 10 and beyond boreholes 14, water is injected into the formation thru boreholes 14 so as to cool the combustion products and produced hydrocarbons thereby lowering the pressure required to force air

thru the stratum from boreholes 12 to the combustion front.

In operating in accordance with the embodiment of the invention illustrated in FIGURE 2, a combustion zone is established around well 10 in conventional manner and the combustion zone is moved radially outwardly from well 10 by inverse air injection thru tubing 22. The injected air has access to the entire wall of borehole 12 within stratum 17 and is confined thereto by packer 20. When the combustion front has advanced thru the stratum a substantial distance from borehole 10, water is injected into permeable stratum 18 thru the annulus around tubing 22 and because of the gas pressure in stratum 17 water does not enter the stratum in this area, but because of the lower pressure behind the combustion front within stratum 17, water does enter this area and effectively reduces the temperature thereof.

In either embodiment of the invention, the rate of water injection is controlled and regulated so that substantially all of the water entering the hot stratum is evaporated but the temperature of the cooled stratum and gases passing therethru is maintained at a level above the dew point or condensation point of the water vapor in the effluent gas. The injection of water may be controlled in response to the temperature of the produced gas or the effluent stream from borehole 10. The temperature of this effluent gas should not be lowered substantially below about 250° F. Since the temperature of the formation behind the combustion front may be as high as 1500 or 1600° F. substantial benefit is derived from the injection of water into the partially burned out area behind the combustion front at a sufficient rate to reduce the temperature therein to 1000° F. and lower. It is found that flow resistance behind the combustion front is reduced as much as 73 percent by injecting water into the hot area so as to reduce the effluent gas temperature to about 300° F. This type of operation involves injecting about 2.42 gallons of water per 1000 s.c. ft. of air when the combustion temperature is approximately 1300° F.

In a radial drive process such as that illustrated in FIGURE 1, most of the flow resistance occurs near the production well and, since this is the region which has reduced flow resistance when operating in accordance with the invention, maximum benefits are obtained when utilizing such a flow pattern.

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. In a process for producing hydrocarbons from a carbonaceous stratum by inverse air injection in situ combustion comprising establishing a combustion zone in said

stratum around a production borehole therein by heating said stratum to combustion supporting temperature and contacting the hot stratum with O₂-containing gas; injecting air into said stratum thru an offset injection borehole and passing same to said combustion zone so as to advance said zone thru said stratum countercurrently to the flow of air; and recovering produced hydrocarbons from said stratum thru said production borehole; the improvement comprising injecting water into a hot burned-over area of said stratum intermediate said combustion zone and said production borehole so as to cool combustion gas and produced hydrocarbons passing thru said stratum to a temperature below about 1000° F. but above the dewpoint of the mixed gases.

2. The process of claim 1 wherein water is injected into said hot area directly thru boreholes leading to said area.

3. The process of claim 1 wherein water is injected into a permeable non-carbonaceous stratum adjacent said carbonaceous stratum thru a borehole thru which the inverse air is injected, whereby flow of said water into said carbonaceous stratum ahead of the combustion zone is substantially prevented by the pressure of said inverse air and said water flows laterally thru said non-carbonaceous stratum to a lower pressure area behind said combustion zone before flowing into said hot area.

4. A process for producing hydrocarbons from a carbonaceous stratum comprising igniting said stratum around a production borehole therein to establish a combustion zone; injecting air into said stratum thru several injection boreholes spaced in a ring around said production borehole and forcing said air to said combustion zone so as to advance a combustion front thru said stratum toward said injection boreholes; recovering produced hydrocarbons and combustion gas thru said production borehole; and after said combustion front has advanced a substantial distance from said production borehole, injecting water into a hot section of said stratum intermediate said combustion front and said production borehole so as to substantially cool the gases passing therethru but not below the condensation temperature of water therein.

5. The process of claim 4 wherein the temperature of the effluent gas in said production borehole is sensed and the injection of water is regulated so as to maintain said gas at a temperature in the range of about 250 to 1000° F.

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