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IN SITU COMBUSTION IN CARBONACEOUS STRATA

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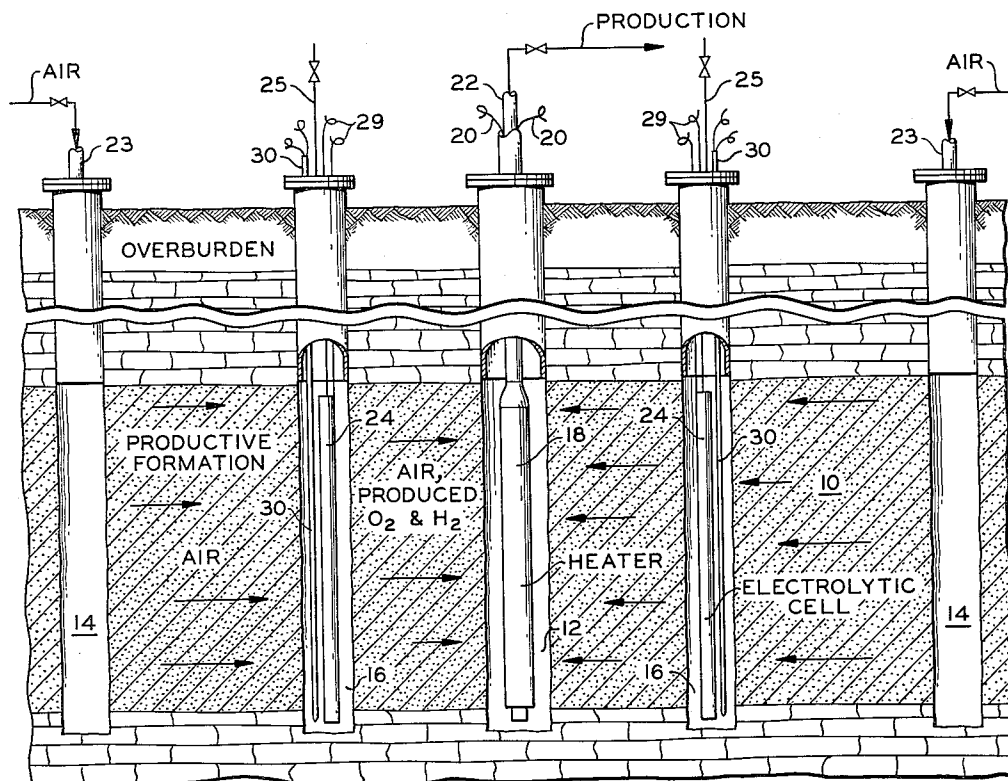


FIG. 1

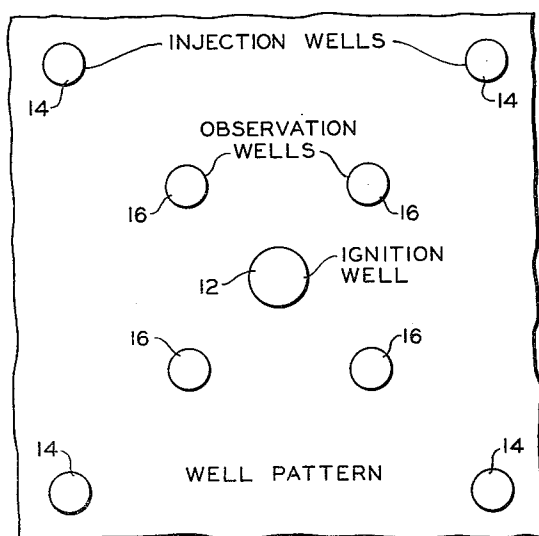


FIG. 2

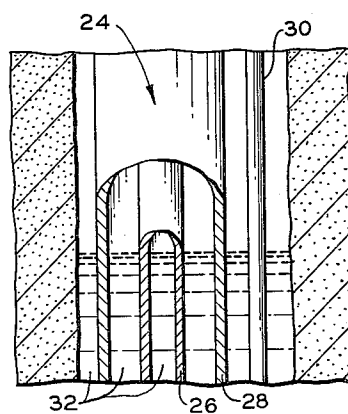


FIG. 3

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## IN SITU COMBUSTION IN CARBONACEOUS STRATA

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This invention relates to a process for producing hydrocarbons from a carbonaceous stratum by in situ combustion. A specific aspect of the inventive process is concerned with simultaneous drying of a borehole in a carbonaceous stratum containing water and supplying  $O_2$  and  $H_2$  to the surrounding stratum for combustion purposes.

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 unburned 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, 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 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 thru the stratum, inverse air injection has been resorted to. By this technique, a combustion zone is established around one or more ignition boreholes by any suitable means and air is fed thru the stratum to the combustion zone from one or more adjacent boreholes.

One of the problems in maintaining continuous underground combustion in a carbonaceous stratum and in initiating combustion therein is the difficulty in providing an adequate supply of oxidizing gas at the point where the combustion is being initiated or continued. Fuel gas in the formation, water vapor, combustion gas, etc., mix with the oxidizing gas (usually air) so as to dilute the same and decrease the  $O_2$  concentration at the point where needed.

When producing hydrocarbons by the in situ combustion technique it is desirable to know the progress of the combustion front and the location thereof at different stages of the process. In order to do this, observation boreholes are drilled at different positions in the path of the combustion front, such as in a ring around an ignition borehole between said borehole and an outer ring of air injection or production boreholes, depending upon whether inverse or direct air injection is utilized in moving the combustion zone. The inner ring of observation holes are provided with thermocouples which indicate the passage of the combustion zone thru or adjacent the hole, in each instance, and thereby provide information on the progress of the combustion process. In field operations, it has been found that these observation wells containing the thermocouples frequently fill up with formation water during the preliminary blowing of air thru the stratum to drive out the water and these holes thereby lose their value in indicating temperature as soon as the boiling point of the water at the existing pressure in the hole is

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reached and until all of the water is boiled off. This may be too long a time in most cases and the combustion front may pass the temperature-indicating hole before all of the water is boiled away.

Accordingly, it is an object of the invention to provide an improved process for effecting in situ combustion of carbonaceous material in a stratum containing same to produce hydrocarbons therefrom. Another object is to provide a process for supplying  $O_2$  and  $H_2$  in situ in a carbonaceous stratum for combustion purposes. A further object is to provide a process for simultaneously drying a temperature sensing borehole in a carbonaceous stratum containing formation water and supplying  $O_2$  and  $H_2$  within the stratum for combustion purposes. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A board aspect of the invention comprises establishing an electrolytic cell in an observation borehole adjacent an ignition borehole and positioned in the path of a combustion front initiated at the ignition borehole and passing a direct electric current thru the cell so as to decompose the water therein, thereby drying the hole and providing  $O_2$  and  $H_2$  in the stratum for combustion purposes. During the water decomposition step, the borehole containing the cell is closed to upward flow so that the gases formed by the decomposition are forced into the stratum. It is also feasible to inject air thru the observation borehole in which the cell is positioned so as to force a continuous stream of oxidizing gas and fuel into the stratum and toward the combustion zone during an inverse air injection in situ combustion process. In such a process, air is injected into the stratum thru boreholes more remote from the ignition borehole than the cell boreholes so that air sweeps decomposition products in the cell boreholes toward the combustion front. The decomposition of water by the electrolysis process is a well known process and needs little discussion here. When effecting water decomposition in an electrolytic cell in which formation water forms the electrolyte, hydrogen, oxygen, and chlorine are liberated. Most water present in carbonaceous strata contains sufficient salt to render the water electrolytic. However, if addition of electrolyte to the water in the borehole assists in the water-decomposition process, salt or other electrolyte can be added to the water in 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, partially in section, showing an arrangement of apparatus and boreholes in a carbonaceous stratum for effecting the process of the invention; FIGURE 2 is a plan view of a well spacing adapted to the process of the invention; and FIGURE 3 is a fragmentary elevation, partially in section, of an electrolytic cell of FIGURE 1.

Referring to FIGURE 1, a carbonaceous stratum 10 is penetrated by an ignition borehole 12 and a series of air injection boreholes 14. When utilizing a ring of boreholes 14 around a central borehole 12, observation boreholes 16 are positioned in a ring around borehole 12 and closely spaced therefrom a short distance, such as 1 to 10 feet, while boreholes 14 are spaced at substantially greater distance from the central borehole, such as 10 to 50 or 100 feet or more.

When utilizing in-line drive of the combustion front a series of in-line boreholes 12 spaced a few feet apart in the line, such as 5 to 50 feet, are drilled thru carbonaceous stratum 10 and a parallel line of boreholes 14 are drilled on one or both sides of the line of ignition boreholes 12. FIGURE 1 therefore represents an elevation generally perpendicular to the line of in-line boreholes and it also represents an elevation thru a ring-type pattern of boreholes as illustrated in FIGURE 2.

Ignition borehole 12 is provided with a heater 18 which may be an electric heater connected by wires 20 to a suitable source of current, or a gas-fired heater, or a mass of incandescent charcoal, or other suitable heating device for raising the temperature of the adjacent stratum to the ignition point of the carbonaceous material therein when contacted with air or other combustion-supporting gas. Well tubing 22 extends to the bottom of borehole 12 for withdrawing product hydrocarbons, combustion gas, etc., in conventional manner. Observation boreholes 16 are provided with electrolytic cells comprising an anode 26 and cathode 28 (FIGURE 3) connected by leads 29 with any suitable source of direct electric current (not shown). A gasoline, diesel, or propane operated motor driving a low voltage, high current D.C. generator (e.g., an electric welder) is an excellent source of current. Each of boreholes 16 is also provided with a thermocouple 30 or other temperature sensing device.

Anode 26 may be constructed in the form of a solid rod of graphite or magnetite or in the form of a hollow porous cylinder and cathode 28 is preferably constructed of a hollow perforate or porous cylinder (open at both ends) of graphite, iron, copper, or nickel. The electrolyte 32 fills the annular space around anode 26 and around cathode 28 as shown in FIGURE 3.

FIGURE 2 shows a ring type pattern of injection wells 14 and observation wells 16 around a central ignition well 12.

In operation of the process a combustion zone is established around borehole 12 by conventional methods, such as by heating the stratum adjacent the borehole by means of heater 18 and, while the carbonaceous stratum is hot, contacting the same with an O<sub>2</sub>-containing gas so as to ignite the carbonaceous material and establish a combustion zone in the section of stratum adjacent the well bore. Air may be injected thru tubing 22 or thru conduits 23 or conduits 25 to supply the air for initiation of combustion. After combustion has been established, the resulting combustion front around borehole 12 is caused to move thru the stratum by injection of air or other combustion-supporting, O<sub>2</sub>-containing gas thru lines 23 serving boreholes 14. One embodiment of the invention comprises passing direct current thru cells 24 during the preheating of the stratum around borehole 12 so as to decompose water in the electrolyte in borehole 16, and preventing flow of gas upwardly thru boreholes 16 so that the produced O<sub>2</sub> and H<sub>2</sub> are forced thru the stratum into the hot area around borehole 12. To facilitate this aspect of the invention air may be injected thru lines 25.

It is also feasible to establish combustion around borehole 12 prior to initiating electrolytic decomposition of water in boreholes 16 and then effect this decomposition after combustion has been established, so as to aid in the movement of the combustion front thru the stratum to the observation boreholes in which the cells are located. Also, the water-decomposition phase of the process may be practiced both during the initiation of combustion and during the movement of the combustion zone thru the stratum toward the observation wells.

When utilizing in-line drive the process is operated in a comparable manner with ignition of the stratum around a series of in-line boreholes 12 and movement of the resulting combustion zone outwardly in both directions toward in-line observation holes 16 and eventually beyond these holes to boreholes 14. After the depletion of the water in the observation boreholes the decomposition of course ceases and the electrolytic cell is withdrawn from

the borehole. This should occur before the combustion zone reaches the observation well.

To illustrate the invention, when a 6 volt direct current is applied to a cell 12 feet long comprising a 4 inch O.D., 3½ inch I.D. outer electrode of porous graphite, and a smaller hollow porous graphite cylindrical inner electrode of 2 inch O.D. and 1½ inch I.D., positioned axially in a 6 inch diameter borehole filled with formation salt water to the top of the cell, about 208 standard cubic feet of H<sub>2</sub> and about 104 s.c.f. of O<sub>2</sub> are liberated per foot of depth with an expenditure of approximately 42.4 kw.h. of electrical energy. Chlorine production amounts to about 0.064 s.c.f. per foot of depth when the concentration of NaCl is 2,000 p.p.m. and 0.64 s.c.f. with a concentration of 20,000 p.p.m.

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 producing hydrocarbons by in situ combustion from a permeable stratum containing carbonaceous material and formation salt water by in situ combustion which comprises igniting said material in a section of said stratum by heating said stratum around an ignition borehole therein to combustion supporting temperature and contacting the hot stratum with O<sub>2</sub> containing, combustion-supporting gas; feeding said gas to the resulting combustion zone thru said stratum from an offset injection borehole therein to move said combustion zone thru said stratum; establishing an electrolytic cell containing formation salt water in a third borehole in said stratum intermediate said injection borehole and said combustion zone; shutting in said third borehole; passing direct electric current thru said cell so as to decompose said water into H<sub>2</sub> and O<sub>2</sub>, whereby injected gas moves said H<sub>2</sub> and O<sub>2</sub> into the said combustion zone to cause same to react and assist in the combustion process; and recovering the produced gases from a borehole in said stratum.

2. The process of claim 1 wherein said ignition borehole is surrounded by a ring of injection boreholes thru which air is injected and electrolysis is effected in several electrolytic cells positioned in third boreholes intermediate said ignition borehole and said injection boreholes.

3. The process of claim 1 wherein air is injected thru an outer ring of injection boreholes surrounding said ignition borehole and is passed to a combustion zone adjacent same; and decomposition of water by electrolysis is effected in cells in an inner ring of boreholes spaced from said ignition borehole a distance in the range of 1 to 10 feet.

4. A process for simultaneously drying a borehole in a carbonaceous stratum containing salt water and supplying O<sub>2</sub> and H<sub>2</sub> to the surrounding stratum for combustion purposes comprising establishing an electrolytic cell in said borehole with said salt water as electrolyte and passing direct electric current thru said cell so as to decompose said water while said borehole is closed to upward flow.

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

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