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A. S. ROGERS ET AL

3,024,013

RECOVERY OF HYDROCARBONS BY IN SITU COMBUSTION

Filed April 24, 1958

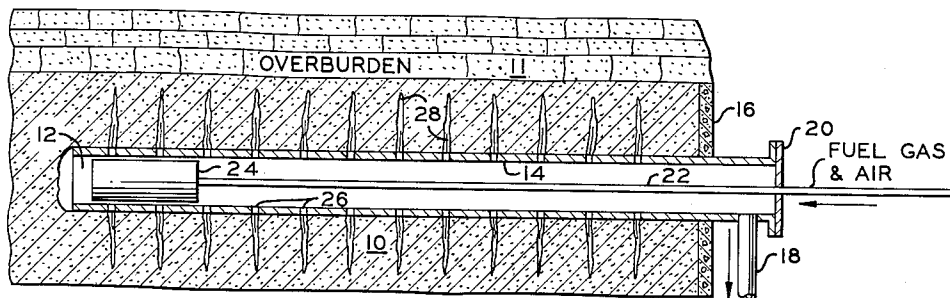


FIG. 1

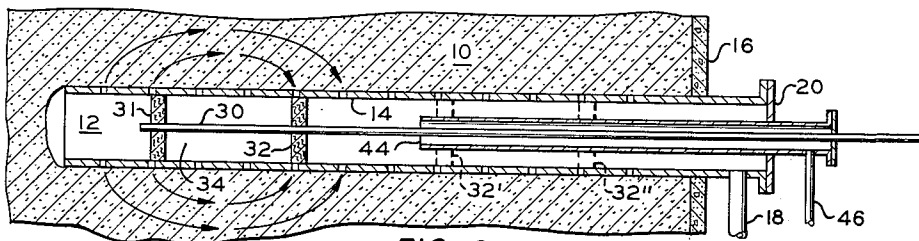


FIG. 2

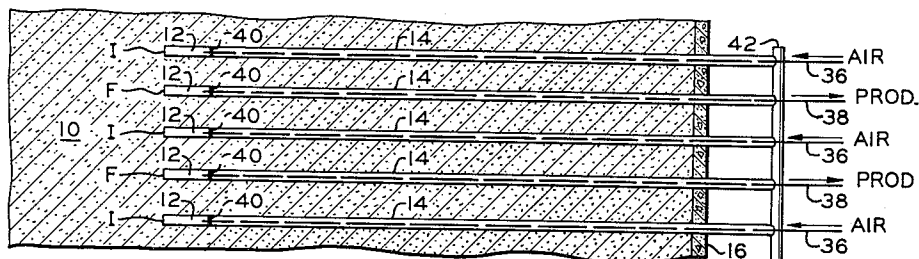


FIG. 3

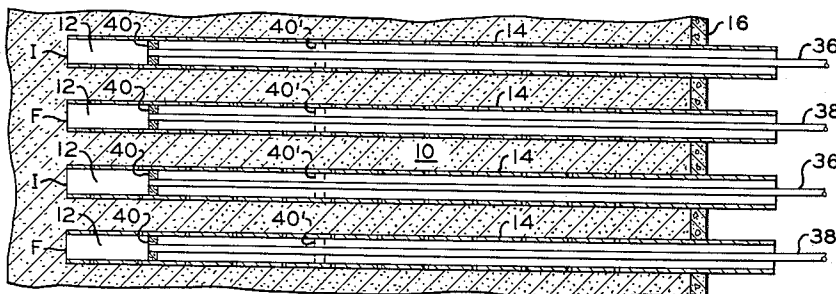


FIG. 4

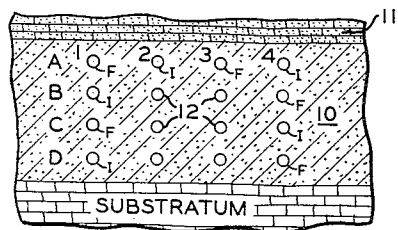


FIG. 5

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3,024,013

RECOVERY OF HYDROCARBONS BY IN SITU
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This invention relates to an improved process for recovering hydrocarbons from a carbonaceous stratum having a transverse face open to the atmosphere.

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 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 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 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.

Several types of carbonaceous strata have been found in various geographical areas which have an open face or outcropping in the side of a mountain, cliff, or canyon. Shale strata of this type are found in Colorado, and lignite coal veins exposed in this manner are found in Montana and the Dakotas. In other areas outcroppings of tar sands have been found. Generally tar sands and shales are relatively impermeable and lignite coal veins, while permeable, are of such low permeability and contain so much bound water in their structure that they require special treatment in order to recover the hydrocarbons therefrom.

Accordingly it is an object of the invention to provide an improved process for recovering hydrocarbons from a generally horizontal carbonaceous stratum having an exposed face thru an upright or inclined earth surface. Another object is to provide a process for recovering hydrocarbons from a carbonaceous stratum thru a vertical face of the stratum without drilling thru the overburden. A further object is to provide a process for recovery of hydrocarbons from a relatively impermeable carbonaceous stratum lying in a generally horizontal plane and open along a vertical face whereby the stratum is rendered permeable and producible by in situ combustion. Other objects of the invention will become apparent from consideration of the accompanying disclosure.

A broad aspect of the invention as applied to a carbonaceous stratum having an exposed transverse face comprises drilling at least one borehole into the stratum generally parallel with its top and bottom surfaces so that the hole drains to the face; thereafter inserting a

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downhole heater on a conduit to the bottom area of the borehole; heating the stratum around the heater so as to fluidize and drive hydrocarbons into the borehole and leave a residual carbonized porous material in the stratum; gradually moving the heater toward the mouth of the borehole while continuing the heating; and recovering fluid hydrocarbons from the mouth of the borehole.

In order to facilitate retorting of hydrocarbon material from the stratum it is advantageous to vertically fracture the stratum around one or several boreholes therein thru casing inserted into the borehole to protect the same from cave-in and from spalling. Fracturing is effected radially outwardly from the borehole by controlled perforation of the casing, packing off a selected area to be fractured, and subjecting the packed off area to fluid pressure in conventional manner. The fracturing may be either parallel with the section of casing packed off or perpendicular thereto. In this manner the stratum surrounding the borehole may be fractured at regular intervals along the length of the borehole in order to facilitate drainage of the fluidized hydrocarbons from the stratum during the heating step. The fracturing is preferably effected along only a section of the borehole or casing prior to the heating and retorting step as applied to that section and thereafter an adjacent section closer to the mouth of the borehole is fractured before subjecting the adjacent section to heating and retorting. This procedure is continued until the mouth of the borehole is reached.

By heating the stratum thru a plurality of generally parallel boreholes spaced a few feet apart, such as 3 to 15 or 25 feet depending upon the character of the stratum, the retorting process is more effective because of lower heat losses to the overburden and underburden than would be effected by heating thru only one borehole at a time.

Another aspect of the invention comprises establishing in situ combustion in the stratum around one or more boreholes, after the retorting step, so as to burn a portion of the carbonized residue left by the retorting step and produce additional hydrocarbons from the residual material. Combustion of the porous residue in the stratum after the heating and retorting step is effected in conventional manner such as by heating the wall of the borehole in the selected area to ignition temperature and contacting the hot stratum with O₂-containing gas, such as air, whereby the carbonaceous residue ignites and the resulting combustion front or zone is moved thru the stratum by feeding air thereto either by inverse or direct injection.

By heating the carbonaceous stratum from the bottom of the borehole toward the mouth thereof, the hot gases and liquids passing out the borehole impart heat to the surrounding stratum on their way out and thereby contribute to the efficiency of the process. However, if the economics of the process are of no consequence it is feasible to heat the borehole from the mouth to the bottom thereof.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is a longitudinal partial section thru a borehole, containing apparatus, in a generally horizontal carbonaceous stratum and illustrating heating and retorting; FIGURE 2 is a similar view illustrating an in situ combustion technique; FIGURE 3 is an elevation thru a carbonaceous stratum showing a borehole arrangement and equipment used in the process; FIGURE 4 is a horizontal view thru a stratum showing the boreholes and equipment, in partial section, for effecting in situ combustion; and FIGURE 5 is an end elevation along the face of the stratum showing a preferred arrangement of boreholes therein.

Referring to FIGURE 1, a carbonaceous stratum 10 is penetrated by a borehole 12 in which is positioned a casing 14 extending substantially to the bottom of the borehole. The face of the borehole is sealed against fluid flow by means of a layer of gunnite 16 or other cementitious sealing material. A drain conduit 18 connects with casing 14 which is provided with a header 20 thru which extends a conduit 22 leading to a heater 24 in the bottom of the hole. Heater 24 may be any type of heater adapted to heat the surrounding borehole to an elevated temperature, such as 400 to 700° F. Downhole gas heaters are available which heat a selected section of the borehole and are supported by fluid cooled conduit means so as to avoid burning off the supporting and supplying heater conduits. Some of these heaters are fired by burning a premixture of fuel gas and air supplied thru a single conduit, while others require separate fuel and air lines. Hence conduit 22 represents any number of conduits required to supply the heater and cool the conduit means. The U.S. patent application of A. S. Rogers et al., S.N. 719,890, filed March 7, 1958, discloses a downhole heater adapted to use in this invention.

Casing 14 is perforate at different depths as at 26 and stratum 10 is fractured thru the perforations as at 28. While fractures perpendicular to the axis of the casing are shown, the same may be parallel to said axis and extending radially from the borehole.

FIGURE 2 shows borehole 12 after retorting and during the initial phase of the in situ combustion procedure. A conduit 30 extends into the borehole to the initial combustion area. Packers 31 and 32 seal off section 34 of the borehole. Other positions of these packers are shown at 32' and 32''. Tubing 44 provides an annulus with tubing 30 for injection of air from line 46.

In FIGURE 3 a stratum 10 adjacent an overburden 11 is penetrated by a series of boreholes 12 provided with casings 14 as in FIGURE 1. The equipment shown is arranged for in situ combustion and includes air lines 36 and production tubing 38 extending to the combustion area of the boreholes downhole from packers 40. A manifold 42 connects the outside ends of casings 14 for recovery of hydrocarbons escaping from the stratum into casings 14 during the in situ combustion process. This manifold is also suitable for recovering retorted hydrocarbons during the heating and retorting step.

FIGURE 4 shows the plan view of the borehole arrangement shown in FIGURE 3.

In FIGURE 5 the boreholes drilled into stratum 10 are shown in a desirable arrangement in horizontal rows A, B, C, and D and vertical columns 1, 2, 3, and 4.

In operating the process, in one or more boreholes as illustrated in FIGURE 1, heater 24 is positioned in the bottom of the borehole and firing is initiated so as to heat the surrounding stratum and fluidize hydrocarbons therein so that they are driven from the stratum into the borehole, the liquids draining to recovery line 18 and the vapors being recovered thru this line also. Borehole 12 is drilled into the stratum for a distance up to about 500 to 800 feet. As the stratum adjacent the bottom of the hole is heated to the desired level in the range of 400 to about 700° F. and the retorting of hydrocarbons therefrom is substantially complete at the temperature reached, heater 24 is moved closer to the mouth of the borehole either continuously or progressively by adjacent sections so as to complete the heating and retorting of the carbonaceous material around the borehole. Downhole gas heaters, as well as electrical heaters, are available to heat a substantial section of the borehole, such as from 15 to 25 or 30 feet, from one position. Since the hot retorted hydrocarbons from the bottom of the hole convey heat to the stratum on their way out of the borehole, the heating times required in the sections of borehole nearer the mouth become progressively less, the section near the mouth of the borehole being subjected

to a shorter preheating period than sections more remote from the mouth of the borehole. During heating and retorting, fractures 28 greatly assist in transferring heat to the more remote sections of the stratum from borehole 12 and in conducting the retorted hydrocarbons from the stratum. It is to be understood that fractures may be created along the entire extent of the borehole either before the retorting or after a portion of the retorting has been completed. The heating and retorting step described in connection with the borehole of FIGURE 1 may be applied simultaneously to any number of boreholes in the stratum, such as in all of the boreholes simultaneously as in FIGURE 5 or in a larger section thereof.

After the retorting of the stratum around borehole 12 has been completed, the bottom hole section of the borehole is ignited in any suitable manner conventional in the art, as by heating the bottom section of the borehole to ignition temperature and supplying air thereto thru conduit 30. The resulting combustion zone or front is then driven thru the stratum by injecting air thereto thru conduit 30 so that the resulting combustion gas and produced hydrocarbons pass thru the stratum around section 34 and return to the borehole outwardly from packer 32 since section 34 of the borehole is not open to tubing 30 or to the surrounding annulus. As the combustion front reaches the vicinity of packer 32 the position of these packers is changed so that 31 is in the original position of packer 32 and packer 32 is in the position shown in dotted lines as 32'. As the combustion front reaches the vicinity of packer 32' the packers are again moved to a position closer to the mouth of the borehole so that packer 31 is in the position of 32' and packer 32 is in the position of 32''. In this manner an area of the stratum surrounding borehole 12 is progressively produced by in situ combustion in the permeable carbonized residue left by the original heating step.

It is also feasible to produce the area around borehole 12 by means of inverse in situ combustion. In this technique of operation, outer concentric conduit 44 extends into the borehole around conduit 30 and is open on the inner end so as to supply air from line 46 to the section of the borehole between packer 32 and the mouth of the borehole. The injected air is forced into the stratum around packer 32 and to the burning stratum beyond packer 31 so that it feeds the combustion front adjacent the bottom of the borehole, thereby advancing the same thru the stratum along the borehole with the combustion gas and produced hydrocarbons passing into the bottom section of the borehole and egressing thru conduit 30 which connects with the recovery system. In this type of operation, packers 31 and 32 are moved along the borehole in a manner similar to that of the direct air injection operation. Of course, tubing 44 is withdrawn partially from the borehole, as required, in order to feed injected air into the stratum between packer 32 and the mouth of the borehole.

In operating the process with a multiplicity of boreholes in horizontal rows and vertical columns as illustrated in FIGURES 3, 4, and 5, it is preferred to produce the hydrocarbons from sections of the stratum between adjacent boreholes starting from the bottom of the boreholes and working toward the mouth thereof. The bottom of alternate boreholes in each row and in each column is ignited after packing off the bottom section of each borehole, and then air or other O₂-containing combustion-supporting gas is injected thru the other alternate boreholes spaced between ignition boreholes so as to move the combustion front by inverse air injection thru the area between adjacent boreholes in each instance. Production is recovered thru the ignition boreholes and the combustion front moves to the injection boreholes. As illustrated in FIGURES 3 and 4, packers 40 close off the bottom section of the boreholes. Conduits 36 supply injected air and production is recovered

thru alternate conduits 38 so that the combustion front moves from the boreholes containing the production conduits 38 to the boreholes containing air injection conduits 36. The air injection and ignition boreholes are alternately positioned so that an ignition borehole is surrounded by injection boreholes. The boreholes in FIGURE 5 are labeled I and F to designate injection and fire holes, respectively, and to illustrate the preferred use of these boreholes during the in situ combustion phase of the process.

It is also feasible to initiate combustion in the boreholes shown as fire holes (F) in FIGURE 5 and drive the combustion front to the adjacent holes designated injection holes (I) which then become production boreholes in a typical direct drive process.

After the production of the stratum adjacent the bottom of the boreholes has been completed, an adjacent section of the stratum along the boreholes is produced by igniting the stratum intermediate packer 40 and packer 40' in the "F" boreholes and injecting air thru line 36 in the "I" boreholes to the packed off section between packers 40 and 40'. In this operation, packers 40 must be solid packers, without axial openings, and conduits 36 and 38 extend merely thru packers 40' so that the injected air or effluent gases must pass thru the packed off sections between packers 40 and 40'. Here again the movement of the combustion front between boreholes may be effected either by direct or inverse air injection. The completion of the production of the stratum around the numerous boreholes is effected in a similar manner by progressively moving the packers toward the mouth of the boreholes as the various sections of stratum adjacent the packed off borehole sections are produced.

The production of the stratum from a given depth to any other given depth along a checkerwork of boreholes therein, section by section, in unbroken continuity, is particularly effective in producing an entire stratum without leaving appreciable residual carbonaceous material in the stratum; and it is also applicable to production of a thick stratum which does not have an outcropping, by boring thru the stratum from the overburden so that the boreholes are substantially vertical.

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.

We claim:

1. A process for recovering liquid and gaseous hydrocarbons from a carbonaceous stratum having an exposed upright face which comprises drilling at least one borehole into said stratum from said face so that it drains to said face; inserting a heater on a conduit to the bottom area of said borehole thru the mouth thereof; heating said stratum around said heater to a temperature in the range of about 400 to 700° F. so as to fluidize and drive liquid and gaseous hydrocarbons into said borehole and leave residual carbonized material in said stratum; thereafter, progressively moving said heater toward the mouth of said borehole and continuing said heating; and draining and recovering said liquid hydrocarbons in liquid form thru the mouth of said borehole along with said gaseous hydrocarbons.

2. The process of claim 1 further comprising establishing in situ combustion in said carbonized material in said stratum adjacent the bottom of said borehole after the heating step; feeding O₂-containing gas to the resulting combustion zone so as to move same thru said stratum toward said face; and recovering hydrocarbons released by said combustion.

3. The process of claim 2 wherein said combustion is effected by packing off said borehole at a pair of spaced points along an O₂ injection conduit; injecting O₂ thru said conduit to the bottom section of said borehole so as to drive the combustion zone thru the permeable stratum surrounding the packed-off area and past same

where the produced hydrocarbons and combustion gases enter said borehole from said stratum; and moving the packed-off area closer to said face as the combustion zone advances.

4. The process of claim 1 including inserting a casing in said borehole extending to its bottom section and perforating said casing and fracturing the surrounding stratum thru the perforations at selected areas along said casing so as to provide for flow of liquid and gaseous hydrocarbons to said casing and heat to said stratum.

5. A process for recovering fluid hydrocarbons from a carbonaceous stratum having an exposed transverse face which comprises drilling a plurality of boreholes into said stratum from said face so that they drain to said face; simultaneously heating said boreholes progressively from the bottom to the mouth thereof to a temperature in the range of about 400 to 700° F. in the absence of O₂ so as to distill hydrocarbons in liquid and gaseous form from said stratum into said boreholes and leave a porous carbonized residue therein; draining said hydrocarbons from said boreholes; and recovering hydrocarbons from said residue by in situ combustion thereof.

6. The process of claim 5 including sealing said face around said boreholes and providing drain conduits from the mouth of each borehole.

7. The process of claim 5 including packing off a section of each borehole; igniting said residue around the packed-off sections of alternate boreholes; and advancing the resulting combustion front thru said stratum to the next adjacent boreholes by feeding O₂ thereto.

8. The process of claim 7 wherein said combustion front is advanced by inverse injection of O₂ thru the adjacent packed off sections.

9. The process of claim 7 wherein said combustion front is advanced by direct injection of O₂ thru the ignition section.

10. The process of claim 7 further comprising progressively moving said packed off sections along said boreholes as the stratum adjacent said sections between said boreholes becomes denuded, so as to produce substantially all of the stratum along and between said boreholes.

11. A process for recovering hydrocarbons from a permeable carbonaceous stratum of substantial thickness which comprises drilling a plurality of closely spaced parallel boreholes therein parallel with the stratum and in a checkerboard pattern; packing off a section of each borehole around a conduit therein at substantially the same depth and closing off said boreholes except thru said conduits; igniting said stratum around alternate boreholes in each direction in said pattern; feeding air to the resulting combustion front around each ignition borehole thru some of said conduits and using others of said conduits as vent conduits so as to move said front to the adjacent boreholes, thereby producing hydrocarbons from sections of the stratum between adjacent packed off sections of said boreholes; and recovering produced hydrocarbons from said vent conduits.

12. The process of claim 11 wherein air is injected thru the conduits in said boreholes adjacent the ignition boreholes so as to move said front inversely to the flow of air and produced hydrocarbons are recovered thru the conduits in said ignition boreholes.

13. The process of claim 11 wherein air is injected thru the conduits in said ignition boreholes so as to move said front by direct drive to the adjacent boreholes and produced hydrocarbons are recovered thru the conduits in said adjacent boreholes.

14. The process of claim 11 including progressively packing off additional sections of said boreholes as the sections of stratum between adjacent packed off sections of bore hole are produced; and producing the additional sections of stratum between the additional packed off sections of borehole in similar manner.

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