This invention relates to a fuel pack for igniting a combustible carbonaceous subterranean stratum and to a method of igniting such a stratum for producing same 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 portion 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 and recovery of produced 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 liquid bank of hydrocarbon collects in the stratum in advance of the combustion zone which prevents movement of air to the combustion zone. 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.

In situ combustion techniques are being applied to tar sands, shale, Athabasca sand and other strata in virgin state, to coal veins by fracturing, and to strata partially depleted by primary and even secondary and tertiary recovery methods.

A common method of igniting a carbonaceous stratum to initiate in situ combustion in the stratum comprises packing the ignition borehole with a fuel pack such as charcoal briquettes, absorbent ceramic pieces soaked with heavy oil, a mixture of pieces of charcoal and porous pieces both soaked with heavy oil or dry, igniting the fuel pack by dropping a charge of red hot charcoal thereon and forcing air down the ignition borehole into the fuel pack so as to burn the same. In another method of igniting one or more burning railroad flares or fuses are dropped onto the pack while air or other O₂-containing combustion-supporting gas is fed into the charcoal pack either thru the ignition borehole or from the surrounding stratum by injection thru one or more offset boreholes.

In relatively thick strata of the order of upwards of 20 feet in thickness, the foregoing methods produce a serious variation in air flow along the axis of the well. For example, when the upper half of the pack has been consumed the carbonaceous stratum above the midpoint of the pay zone has been ignited and the resistance to air flow in this upper half of the pay zone is considerably less than in the region where the formation has not been ignited. As a result, the air flow into the upper half is greater than into the lower half and this process is self-accelerating. As the process is continued the point is finally reached where the lower regions of the pay zone receive insufficient air to ignite the formation.

It is, of course, desirable to establish a combustion front across the entire thickness of the pay zone within a short period and drive the combustion front thru the stratum as uniformly as possible. When igniting the fuel pack on its top surface and driving the combustion zone downwardly there thru by either direct or inverse air injection, the adjacent stratum is ignited first at the top and this initial ignition area moves into the stratum long before the lower sections of the stratum are ignited. This results in establishing an uneven combustion front and the driving of the combustion front thru the upper sections of the stratum considerably faster than is the case in the lower sections of the stratum.

This invention is directed to a fuel pack arrangement and a method of igniting a fuel pack to remedy the foregoing problems.

Accordingly, a principal object of the invention is to provide a fuel pack arrangement and an ignition process which facilitates ignition of the entire fuel pack within a short period of time so as to establish combustion in the adjacent stratum in which the fuel pack is positioned substantially simultaneously across the entire thickness of stratum. Another object is to effect a more rapid and more uniform initiation of combustion in a carbonaceous stratum preparatory to producing same by in situ combustion. Other objects of the invention will become apparent upon consideration of the accompanying description and drawings.

A broad aspect of the invention comprises simultaneously igniting a fuel pack in an ignition borehole along the length of the fuel pack at a plurality of regions therein. In order to accomplish this purpose the ignition borehole is packed with a mass of fuel in which igniters are positioned at regular intervals along the length of the pack longitudinally of the borehole and with means provided for either simultaneously activating the igniters or sequentially activating them at short intervals of time so as to effect the ignition of the fuel pack from end to end before any complete burning of any substantial section of the fuel pack takes place.

In one embodiment of the invention, igniters in the form of incendiary elements such as railroad flares, small charges of unpacked or loose gun powder, or other pyrotechnics are positioned in the fuel pack at regular intervals from the top to the bottom sections, such as every 2 to 10 feet, and are provided with fuses connecting one to the other, with a fuse extending thru the top of the fuel pack, or each with separate fuses extending thru the top of the fuel pack, by dropping any kind of an ignitor on top of the fuel pack, such as a burning fuse, or hot charcoal, or by electric spark, or any other suitable igniting technique or device, the fuse (or fuses) leading to the igniters is ignited and the igniters are quickly activated so as to burn and heat up the surrounding fuel pack to combustion supporting temperatures. Injection of air or other combustion-supporting gas, either thru the ignition borehole or thru the stratum into the fuel pack by injection thru offset boreholes, then feeds the fire established in the fuel pack so as to simultaneously burn the same thruout its length.

In lieu of the incendiary or pyrotechnics type of ignitor, it is also feasible to position electrical resistance heaters or gas heaters at regularly spaced points along the length of the fuel pack so as to effect a similar type of ignition by heating the surrounding fuel pack to combustion-supporting temperature and feeding air or other combustion-supporting gas into the fuel pack.

A more complete understanding of the invention may be had from consideration of the accompanying schematic drawing of which FIGURE 1 is an elevation thru a
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stratum showing one arrangement of a fuel pack and apparatus for igniting a carbonaceous stratum; FIGURE 2 is an elevation thru a fuel pack showing an electrical heating element for igniting a fuel pack; FIGURE 3 is a similar view showing an arrangement of electrical igniters; and FIGURE 4 is a similar view showing a gas burner arrangement for igniting a fuel pack.

Referring to FIGURE 1 a carbonaceous stratum 10 lies between overburden 12 and substratum 14 and is penetrated by borehole 16. A casing 18 extends from wellhead 20 down to the approximate upper level of stratum 10 and is provided with a production line 22 and with an air injection line 24. Production line 22 generally extends to the approximate level of the upper face of the stratum or fuel pack.

A fuel pack 26 fills the borehole within stratum 10 and may extend above the upper level of the stratum particularly when utilizing a charcoal pack without any other filling material therein. In this case, the casing should not extend appreciably below the top of the fuel pack. Igniters 28 are positioned longitudinally of the fuel pack preferably at regular intervals and are connected by a fuse 30 with each other and with an ignition point to the fuel pack. Obviously the fuse may extend to the well head for ignition purposes, but it may be ignited on the top of the fuel pack by any suitable method, such as by dropping an ignited incendiar device on to the top of the fuel pack. The igniters are shown near the outside of the fuel pack but they may be positioned axially thereof with equal effectiveness.

FIGURE 2 shows a resistance heating coil 32 extending from the top to the bottom of the fuel pack which is grounded at 34 and at 36 thru generator or current source 38. A 60 cycle current is suitable for heating coil 32 to temperatures required for ignition of the adjacent fuel pack.

FIGURE 3 shows a pair of leads 40 and 42 across which are connected resistance elements 44 which are positioned at regular intervals within fuel pack 26. Leads 40 and 42 are connected with a suitable current source, such as a 60 cycle frequency (not shown) and capable of heating resistance elements 44 to a temperature sufficient to ignite the adjacent fuel pack.

In FIGURE 4 a gas line or conduit 50 extends thru the fuel pack and is provided with jets 52 spaced regularly along the length of the line. These jets may be in line or staggered around the circumference of the conduit or they may be positioned in rows on opposite sides of the conduit. A sparking device 56 is positioned at the upper end of the row of jets and is connected thru the well head by means of line 58 with a current source (not shown).

Element 56 may comprise an ordinary spark plug.

When utilizing the arrangement shown in FIGURE 1, it is preferred to inject air slowly thru the stratum into borehole 16 from injection wells (not shown) after preliminary dewatering of the stratum by gas pressure. When air is passing into the fuel pack, the fuse extending thru the pack is ignited by dropping a railroad fuse onto it and the igniters are ignited within a few seconds so as to heat the pieces in fuel pack in contact with the igniters and in the vicinity thereof to well above ignition temperature so that the incoming air effects combustion of the fuel pack in the immediate vicinity of the igniters to facilitate the initiation of combustion when utilizing inverse ignition, it is preferable to include in the injected air a small concentration of fuel gas such as propane, natural gas, or LPG, the concentration being in the range of 1 to 3 or 4 percent by volume of the injected gas. The feature of the process greatly assists in moving the combustion zone into the stratum. As the fuel pack is consumed by combustion fed by the incoming air, the combustion spreads thru the fuel pack to the adjacent stratum and is then propagated into the stratum so that inverse in situ combustion of the stratum is established. During the combustion of the fuel pack and the in situ combustion process, effluent gases are recovered thru production line 22.

It is also feasible to inject air thru the fuel pack from the top by forcing air thru line 24 into the casing. This method is called direct air injection and may be utilized in establishing combustion in the stratum around the fuel pack where the stratum is of such character that plugging by reduction in permeability is not affected. In strata containing heavy liquid and semi-solid and solid hydrocarbons, direct drive ignition is inoperative because of the plugging of the stratum by driving liquefied hydrocarbons into the stratum in advance of the combustion front where they compact and reduce permeability below an operable level. Operation of combustion thereof device of FIGURES 2 and 3 is similar to that described in connection with FIGURE 1, the only difference being in the heating of coil 32 or resistance elements 44 by passing current therethru to heat the same to at least red heat to ignite the pyrotechnic igniters of FIGURE 1. Air fed to the heated areas of the fuel pack either thru the ignition borehole or thru the stratum is practiced in the same manner as in FIGURE 1.

When operating with the arrangement of FIGURE 4, a combustible mixture of air and fuel gas is fed thru line 50 and thru jets 52 into the fuel pack and the ignition being effected by sparking device 56. Here again, air is injected in the same manner as heretofore described. It is also feasible to inject excess air thru line 50 to assist in the combustion of the fuel pack. After the fuel pack is ignited and a self-sustaining combustion has been effected, line 50 may be withdrawn from the fuel pack so as to avoid its destruction.

In any of the embodiments of the process described, the ignitor needs to function only a short period such as 3 to 10 minutes in order to raise the temperature of the surrounding fuel pack aggregates to the heat so that contacting air effects immediate combustion thereof.

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.

1. A borehole pack for igniting a combustible carbonaceous stratum comprising a mass of particulate solid fuel filling an elongated section of a borehole within said stratum; a plurality of igniters entirely within said mass spaced equally along the length of the borehole at intervals from adjacent one end to adjacent other end of said mass; means for igniting said igniters so as to ignite said mass adjacent each ignitor; and means for supplying combustion-supporting gas to the ignitor areas.

2. The pack of claim 1 wherein said igniters comprise incendiar ignitors connected by a fuse to each other, said fuse extending to a level above the fuel pack within said borehole.

3. The pack of claim 1 wherein said fuel comprises charcoal.

4. The pack of claim 1 wherein said fuel comprises oil-soaked charcoal.

5. The pack of claim 1 wherein said fuel comprises a mixture of charcoal and adsorbent ceramic pieces.

6. The pack of claim 1 wherein said borehole is substantially upright and said mass of fuel extends from the top section to the bottom section of said stratum.

7. A process for quickly and simultaneously igniting a selected elongated section of a carbonaceous stratum along the wall of a borehole therein which comprises simultaneously igniting an elongated permeable fuel pack in a selected section of said borehole at a plurality of regions at frequent intervals along the length of said fuel pack by heating said regions to combustion-supporting temperature and effecting combustion-supporting gas thereto; continuing the injection of said gas so as to continue the burning of said fuel pack along its entire length and to heat the adjacent
stratum substantially simultaneously completely along the fuel pack to combustion-supporting temperature; and contacting the hot stratum with said gas so as to substantially simultaneously ignite the entire selected section of stratum.

8. The process of claim 7 wherein said fuel pack is heated by passing current thru electrical resistance elements at each said region.

9. The process of claim 7 wherein said fuel pack is heated by burning jets of gas at each said region.

10. The process of claim 7 wherein said fuel pack is coextensive with said stratum so as to ignite the full thickness of stratum.

11. The process of claim 7 wherein said gas is injected into said fuel pack thru said borehole.

12. The process of claim 7 wherein said gas is injected into the fuel pack from said stratum and said gas includes a minor amount of fuel gas.

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