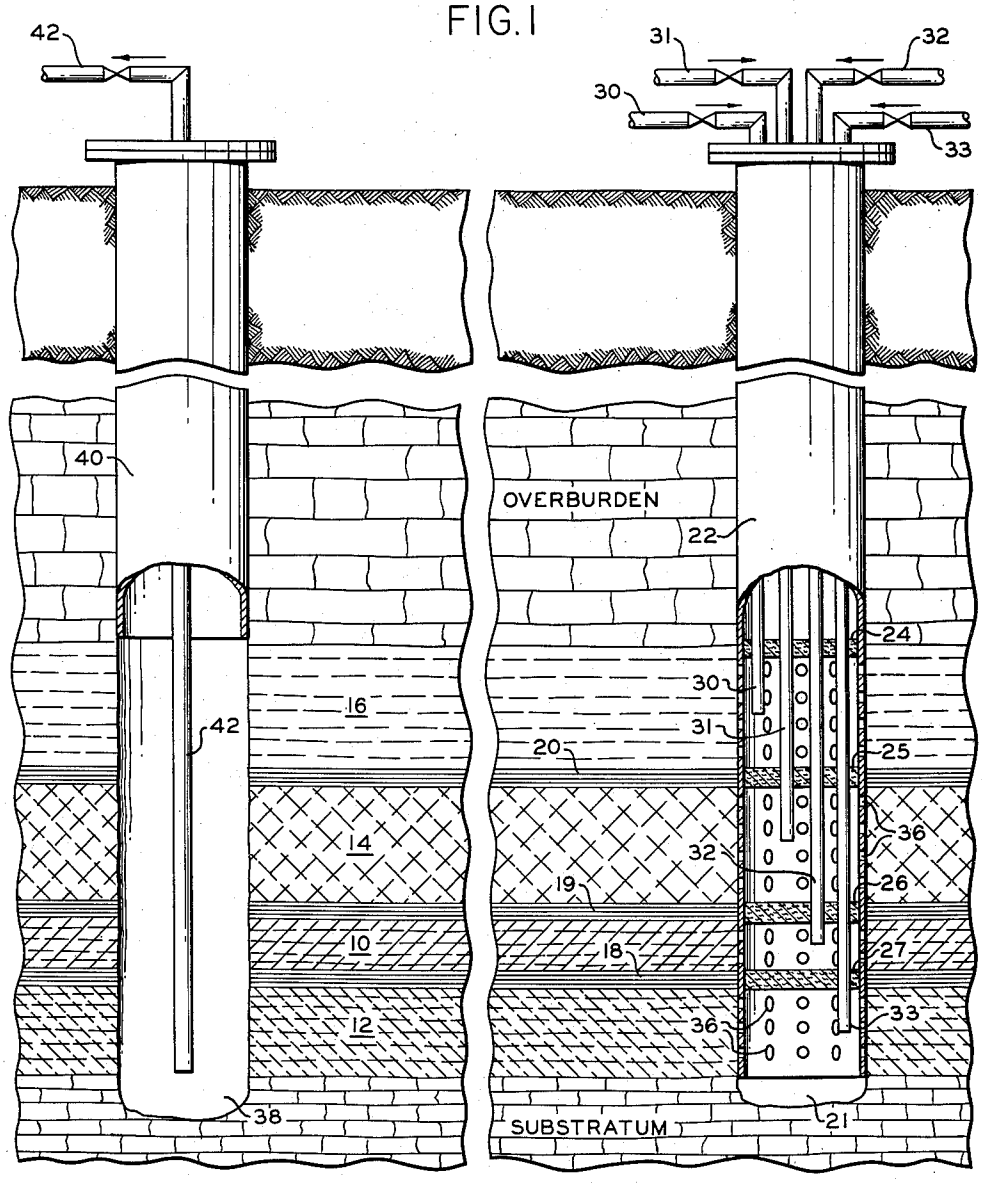
Jan. 7, 1964 H. PURRE 3,116,792

IN SITU COMBUSTION PROCESS

Filed July 27, 1959

FIG. 1



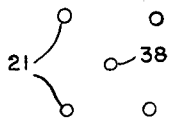


FIG. 2

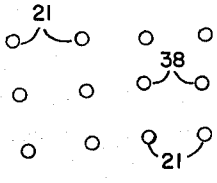


FIG. 3

INVENTOR.
HEINO PURRE

BY Hudson & Young

ATTORNEYS

United States Patent Office 3,116,792 Patented Jan. 7, 1964

3,116,792

IN SITU COMBUSTION PROCESS

Heino Purre, Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware

Filed July 27, 1959, Ser. No. 829,925
10 Claims. (Cl. 166—11)

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 through the stratum by either inverse or direct air drive whereby the heat of combusion 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, consitiutes 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.

Frequently reservoirs or strata to be produced by in situ combustion consists of several layers of different permeability with relatively thin impermeable layers of shale separating the permeable layers. Thus, individual layers of tar sand deposits vary considerably in permeability. In some cases the permeability of a layer is so low that it is impractical to produce by conventional in situ combustion procedures. This invention provides a method of producing layers of low permeability lying in a carbonaceous stratum adjacent a layer of relatively high permeability and separated therefrom by an impervious layer.

It is accordingly an object of the invention to provide an improved process for producing a carbonaceous stratum composed of a plurality of layers of different permeabilities by in situ combustion. Another object is to provide an in situ combustion process for producing a series of permeable layers of different permeabilities in a carbonaceous stratum in which the layers are separated by impervious strata whereby the layers are produced in succession. A further object is to provide an in situ combustion process which utilizes the heat produced in one layer of a stratum for partially producing an adjacent second layer and conditioning said second layer for in situ combustion. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises producing a layer of relatively high permeability in a carbonaceous stratum by in situ combustion so as to heat an adjacent carbonaceous layer of lower permeability and lower the viscosity of hydrocarbons in the latter; producing the thus heated layer by gas drive so as to flush fluid hydrocarbons therefrom; and thereafter producing the remaining hydrocarbon in said layer by in situ combustion. It

is preferred to produce the layer of high permeability by inverse air injection to a combustion zone around a production borehole therein from one or more air injection boreholes, whereby a combustion front is caused to pass thru the layer countercurrently to the flow of air toward the production borehole. The inverse injection in situ combustion process always leaves a carbonaceous residue in the stratum and this can be readily produced by continuing the injection of air thru the injection borehole, after arrival of the front, so that the combustion front is driven back thru the stratum by direct air drive.

The adjacent layer or layers are heated several hundred degrees by the in situ combustion of the highly permeable layer and hydrocarbons can be readily produced therefrom by gas drive such as pressuring with air thru an injection borehole and recovering hydrocarbons flushed out by the passage of air thru the stratum to a production borehole. In most cases, it is desirable to commence the gas drive phase of the process thru the adjacent layer or layers after the combustion front has moved thru the highly permeable layer and back to the production borehole, since the adjacent layers will be at a higher temperature than after one burn thru. However, the gas drive phase of the process may be initiated at any time after the first burn thru. It is also feasible in a highly permeable layer to drive the combustion front thru the layer by direct drive, if this can be done without blocking the flow of gas as frequenly happens in strata of relatively low permeability and containing hydrocarbon of low gravity. At any rate, the flushing of hydrocarbons from the hot adjacent stratum or layer can be effected any time after a single burn thru.

After the flushing phase of the process, in situ combustion of the remaining hydrocarbons in the flushed layer is effected either by direct or inverse air drive, depending upon the character of the resulting layer as to permeability and hydrocarbon content. In most instances it will be preferable to produce this partially produced layer by inverse air injection followed by direct air drive to completely denude the layer. After producing the second layer, the next adjacent layer is ready for production by fluid drive and then by in situ combustion.

When utilizing air as the injection and flushing gas in the adjacent hot stratum, ignition of the stratum is effected by many instances because this stratum is at combustion supporting temperatures. When ignition is effected in this manner, the in situ combustion phase and the flushing phase occur simultaneously. The produced gases (including combustion gases) flush out liquified hydrocarbons from the hot stratum without danger of plugging by congealing because of the high temperature of the stratum thru which they pass.

After combustion has been initiated around an injection well by injection of air (or other combustion-supporting gas), the flow of air may be reversed so as to move the combustion zone thru the hot stratum inversely to the flow of air.

In instances in which ignition does not automatically take place when injecting air into the heated stratum adjacent the burned-over stratum, ignition may be effected by conventional methods, such as heating the stratum around an injection or production well while passing combustion-supporting gas (air alone or admixed with a small concentration of fuel gas) to the heated area.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is an elevation in partial section of an arrangement of apparatus in boreholes in a carbonaceous stratum for effecting one embodiment of the invention; FIGURE 2 is a plan of a 5-spot pattern; and FIGURE 3 is a plan of an in-line well pattern.

Referring to the drawing, layers of a carbonaceous stratum 10, 12, 14, and 16 (numbered in their order of permeabilities) are separated by impermeable shale layers 18, 19, and 20. These layers are penetrated by borehole 21 which is provided with a casing 22. Packers 24, 25, 26, and 27 pack off sections of casing opposite the different layers to be produced. Well tubings 30, 31, 32 and 33 communicate with the various packed off sections in order from top to bottom within the casing. Casing 22 is perforated in the different packed off sections thru perforations 36. A production borehole 38 spaced apart from injection borehole 21 a suitable distance within the range of 10 or 15 feet to several hundred feet, depending upon the permeability of the most permeable layer 10, is provided with a casing 40 extending to the top level of the upper layer 16. Production tubing 42 extends thru the well head to a lower level of borehole 38.

The arrangement of boreholes represents two different types of borehole spacing and production. In one type, illustrated in FIGURE 2, borehole 38 is a central well of a 5, 7, or 9-spot well pattern wherein it is surrounded by a ring of injection boreholes 21 in conventional manner. The drawing also represents a line drive process wherein borehole 38 is one of a series of in-line ignition (and production) boreholes flanked on each side by a line of injection boreholes 21 parallel, or generally so, with respect to the line of production boreholes, so that a combustion zone established around each borehole 38 is advanced radially outwardly in opposite directions toward both lines of injection boreholes. The latter arrangement is shown in FIGURE 3.

In either well pattern, a fire is initiated in a carbonaceous layer by conventional means around borehole 38 and air is passed thru the stratum from the injection borehole 21 so as to feed the combustion zone and cause the same to move to the injection borehole. In instances where direct air drive is utilized initially, the injection of air takes place thru borehole 38 and the other borehole serves as a production borehole.

In utilizing the apparatus shown in the drawing, assuming that layer 10 is the most highly permeable layer, combustion is initiated in layer 10 within borehole 38 by heating the stratum at layer 10 adjacent the borehole to combustion supporting temperature by means of an electric heater, a gas fired heater, a mass of burning fuel in the borehole adjacent layer 10, or by other means, and feeding air or other O_2-containing combustion-supporting gas, such as oxygen enriched air, pure oxygen, or diluted air so as to initiate the combustion of in-place hydrocarbons in layer 10. In some instances it is desirable to inject air thru layer 10 from borehole 21 thru tubing 32 during ignition. It has been found effective to inject a premix of air containing from about 1 to about 3 volume percent of propane or other fuel gas. When in situ combustion is established in layer 10 around borehole 38 injection of air thru tubing 32 (if not already commenced) and thru the layer feeds the combustion zone and causes the same to move thru the layer to the injection well.

When the combustion front arrives at the wall of borehole 21, continued injection of air causes the combustion front to reverse itself and pass back thru the stratum feeding on the hydrocarbon residue remaining from the first burning phase. In actual field tests it has been found that approximately 25 percent of the in-place hydrocarbon material is produced during the first burning phase and substantially the same amount is produced during the second burning phase, so as to recover at least about 50 percent of the in-place hydrocarbons. While the description is directed to operation between the production borehole 38 and an injection borehole 21, in actual practice, with a 5, 7, or 9-spot well pattern the combustion zone moves outwardly laterally from borehole 38 to the several injection boreholes; and, where a line drive process is being utilized, the combustion fronts move outwardly toward the line of injection wells on either side of the line of production wells thereby burning thru a vast area of layer 10 depending upon the number of wells and the spacing thereof.

During the traversal of layer 10 by the combustion front in both burning phases, layers 12 and 14 are heated several hundred degrees depending upon the thickness of layer 10 and the character of the hydrocarbon or other carbonaceous deposit therein. This heating fluidizes and renders less viscous the hydrocarbon material within these layers so that it is feasible to drive fluidized hydrocarbons therefrom by injecting a gas such as air, natural gas, propane (or other natural gas constituents), or any other inert gas under the conditions of operation thru tubing 31 and tubing 33, whereby fluid hydrocarbons are driven into borehole 38 from which they are recovered thru tubing 42 in conventional manner. The driving out of fluid hydrocarbons from layers 12 and 14 increases the permeability thereof so that they are readily amenable to production by in situ combustion and are so produced either by direct or inverse drive, preferably the latter, as described in connection with the production of layer 10. After producing layer 14 by in situ combustion, layer 16 is substantially heated and is ready for partial production by gas drive after which it is produced by in situ combustion in similar manner to the in situ combustion production of the other layers.

It is to be understood that the permeable burned-out stratum first produced is plugged or packed off after production thereof is completed to avoid passing injected gases into this stratum during the production of adjacent strata.

This application is a continuation-in-part of my copending application, S.N. 736,151, filed May 19, 1958, now abandoned.

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 from a plurality of readily combustible underground oil-bearing layers ranging from relatively high to relatively low natural permeability, wherein each pair of adjacent layers is separated by a relatively thin impermeable layer, which comprises separately producing a layer of high permeability by igniting a section thereof around a well therein, feeding O_2-containing combustion-supporting gas to the ignited zone, and continuing the injection of said gas so as to move said zone to another well therein, whereby at least one adjacent less permeable layer is heated so as to reduce the viscosity of hydrocarbons therein; thereafter, while said adjacent layer is hot, producing same by gas drive including injecting a relatively inert non-hydrocarbon gas continuously through one of said wells into said less permeable layer and producing gas and hydrocarbons through the other well, thereby increasing the permeability thereof; and producing last said layer by in situ combustion including igniting last layer around one of said wells and injecting combustion-supporting gas into the ignited area through one of said wells so as to produce hydrocarbons through the other well.

2. The process of claim 1 wherein said layer of high permeability is separately produced by inverse air injection so as to drive a combustion front therethru from a production well toward an injection well.

3. The process of claim 2 wherein separately producing said layer of high permeability comprises additionally driving a combustion front back thru said layer from said injection well to said production well in a second burning phase before producing the adjacent layer by in situ combustion.

4. The process of claim 1 wherein separately producing

said layer of high permeability comprises passing a combustion front thru said layer of high permeability from a production well to an injection well by inverse drive and then back to said production well by direct drive, and production of said adjacent layer by gas drive is initiated before the end of the in situ combustion in first said layer.

5. The process of claim 1 wherein separately producing said layer of high permeability comprises igniting same around a production well therein and passing air thru said layer to the resulting combustion zone from a ring of injection wells around said production well so as to move said zone to the injection wells.

6. The process of claim 1 wherein separately producing said layer of high permeability comprises igniting same around a series of in-line production wells therethru and passing air to the resulting combustion zones from two lines of injection wells, one on each side of the line of production wells, so as to move the combustion zones to said injection wells.

7. A process for producing hydrocarbons from a plurality of readily combustible underground oil-bearing layers ranging from relatively high to relatively low natural permeability, wherein each pair of adjacent layers is separated by a relatively thin impermeable layer, which comprises separately producing a layer of high permeability by igniting a section thereof around a first well therein, feeding O_2-containing combustion-supporting gas to the ignited zone, and continuing the injection of said gas so as to move said zone to a second well therein, whereby at least one adjacent less permeable layer is heated to combustion supporting temperature so as to reduce the viscosity of hydrocarbons therein; thereafter, while said adjacent layer is at said temperature continuously injecting O_2-containing, combustion-supporting gas into same thru one of said wells at combustion supporting temperature within said adjacent layer so as to burn a portion of the hydrocarbons therein and produce a remaining portion thru the other well; and recovering the produced hydrocarbons.

8. The process of claim 7 wherein said adjacent layer at combustion-supporting temperature is ignited around a well therein by air injection thru one of the wells therein and production of hydrocarbons thru the other so as to drive a combustion front thru said adjacent layer.

9. The process of claim 8 wherein ignition of said adjacent layer is effected around a production well and air is injected thru an offset injection well so that the resulting combustion front is advanced thru said hot layer inversely to air flow.

10. The process of claim 8 wherein ignition of said adjacent layer is effected around an injection well and air is injected thru said injection well so that the resulting combustion front is advanced thru sad layer by direct drive toward a production well therein.

References Cited in the file of this patent

UNITED STATES PATENTS

2,382,471	Frey	Aug. 14, 1945
2,584,605	Merriam et al.	Feb. 5, 1952
2,734,579	Elkins	Feb. 14, 1956
2,818,117	Koch	Dec. 31, 1957
2,877,847	Pelzer et al.	Mar. 17, 1959
2,888,987	Parker	June 2, 1959
2,917,112	Trantham	Dec. 15, 1959
2,917,296	Prentiss et al.	Dec. 15, 1959