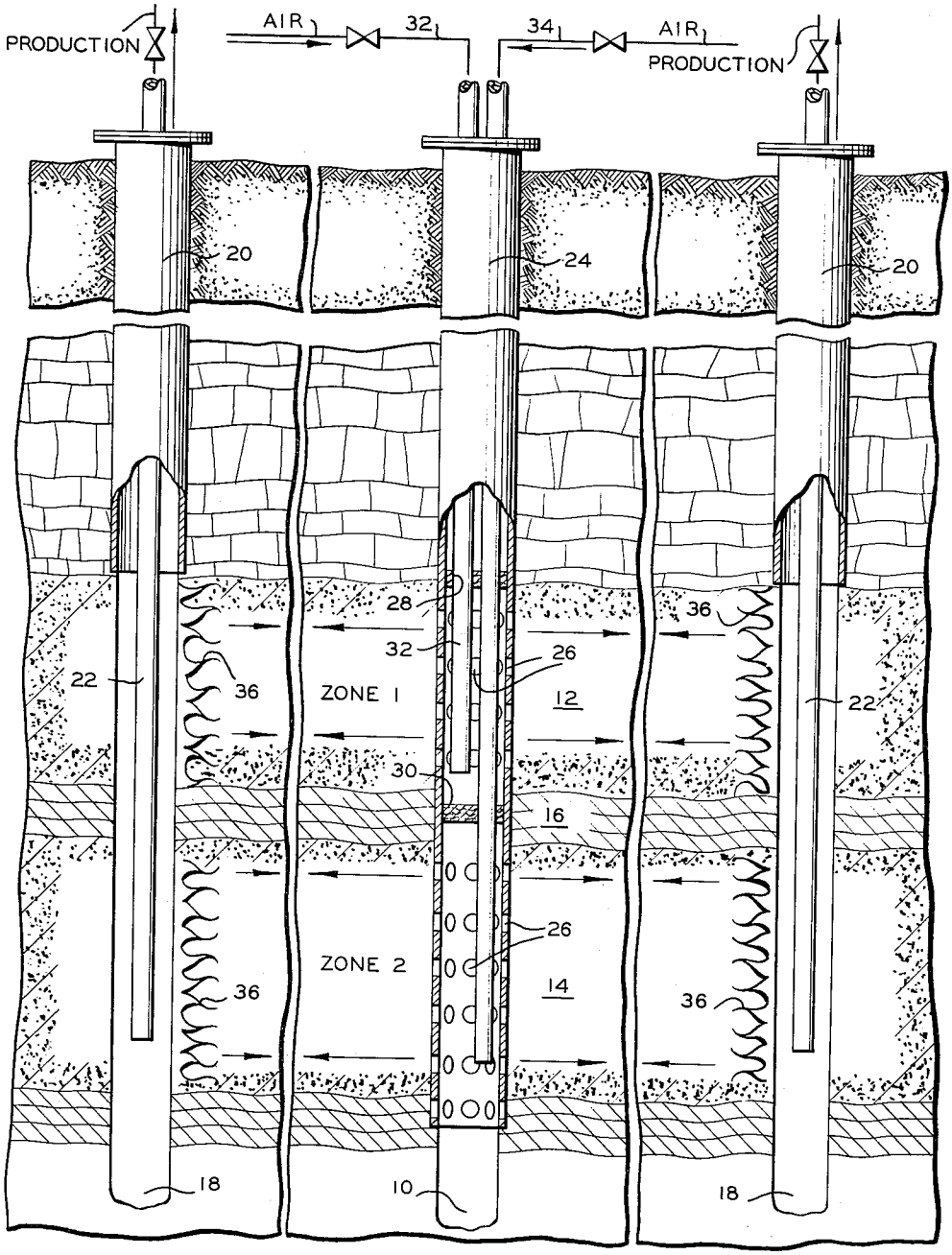
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MULTIPLE ZONE PRODUCTION BY IN SITU COMBUSTION

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MULTIPLE ZONE PRODUCTION 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 through 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, in the inverse drive process, upgrades a substantial proportion of the unburned hydrocarbon material.

The ignition of carbonaceous material in a stratum around a bore hole therein, followed by injection of air through the ignition 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 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 consist of several layers of different permeability with impermeable thin layers of shale separating the permeable layers. Thus, individual layers of tar sand deposits vary considerably in permeability. During the in situ combustion process, utilizing inverse air injection, the different permeabilities of the layers cause the combustion front to travel at different speeds in the different layers. In a very permeable layer, the combustion zone can move the entire distance from a production to an injection well while the combustion zone in less permeable layers travels only a portion of the distance between the wells. This creates a difficult problem in completing the combustion of the various layers in the carbonaceous stratum being produced. With one layer burned completely thru between boreholes most of the injected air passes thru this layer to the detriment of combustion in other layers in which the combustion zone is still in the stratum between the production well and the several injection wells.

This invention is concerned with a method of producing such a stratum by inverse in situ combustion which effects more nearly uniform movement of the combustion fronts thru the various layers of the carbonaceous stratum than would normally occur.

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 utilizing inverse air injection in a stratum containing layers of different permeabilities which at least substantially overcomes the variations in permeability. A further object is to provide an inverse air injection in situ combustion process applicable to a carbonaceous stratum composed of layers of different permeabilities which effects more nearly uniform flow rates of air thru the different layers than would normally occur. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises feeding injected air to a plurality of layers of different permeability in a carbonaceous stratum at different pressures which compensate at least in part for the differences in permeability so as to move a combustion front thru the layers at more nearly uniform rates than would occur with uniform air injection pressures on the different layers. In order to facilitate the process different layers of different permeabilities in a carbonaceous stratum are separately packed off by means of packers positioned in an injection borehole by conventional procedure and providing a separate injection conduit to each packed off section whereby the control of the pressure on each layer may be independently regulated. Combustion is then initiated around a production borehole spaced apart from the injection borehole and the resulting combustion front is advanced thru the separate layers by injecting air into these layers thru the injection borehole at controlled pressures, higher pressures being applied to the layers of lower permeability and vice versa.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing which is a view in elevation, partially in section, of an arrangement of boreholes and apparatus in a multi-layer carbonaceous stratum in accordance with one embodiment of the invention.

Referring to the drawing, an injection borehole **10** passes thru a carbonaceous stratum comprising layer **12** of relatively high permeability and layer **14** of relatively low permeability separated by an impervious thin layer **16**. The stratum is also penetrated by a pair of ignition or production boreholes **18** each provided with a casing **20**, extending down to the upper level of layer **12**, and with a production tubing **22**. A casing **24** in borehole **10** extends thru both layers **12** and **14** and is perforate throughout each of these layers as indicated by perforations **26**. Casing **24** is packed off opposite layer **12** by packers **28** and **30**, positioned at the upper and lower levels of the layer, respectively, and air injection tubing string **32** passes thru packer **28** to supply air to layer **12**. A second air injection tubing string **34** passes thru packers **28** and **30** so as to separately supply air to layer **14**. In this manner, air may be separately injected into layers **12** and **14** at different pressures inversely proportional to their permeability so as to feed air thru these layers to the spaced-apart production boreholes at substantially the same rates per square foot of vertical cross section. If additional layers requiring different pressures are located in the carbonaceous stratum, these may also be separately supplied with injection air by properly packing off the air injection borehole in a manner similar to that shown in the drawing. A combustion front or zone is shown moving away from ignition or production wells **18** toward air injection well **10**.

The arrangement of boreholes shown in the drawing may represent a line of in-line boreholes **10** flanked on each side by a line of production boreholes **18** parallel thereto with a line of injection boreholes (not shown) beyond each of the line of production boreholes **18**. Injection borehole **10** may also be one of a ring of injection boreholes surrounding production borehole **18**. In other words borehole **10** may be common to two rings of injection boreholes each surrounding a production borehole **18**.

In operation with the arrangement shown in the drawing, combustion is initiated around boreholes **18** in both

layers **12** and **14** in any suitable manner such as by packing the boreholes with charcoal, igniting the charcoal and injecting air (or air and fuel gas) thru the bed of charcoal so as to raise the temperature of the surrounding stratum to combustion supporting temperature, and contacting the hot stratum with O_2 (air) so as to burn in-place hydrocarbon and establish in situ combustion. Air is then injected at suitable pressures, preferably inversely proportional to the permeabilities of the layers of stratum, thru air injection conduits **32** and **34** whereby the injected air passes thru the layers to the combustion front **36** and moves the same thru the layers toward borehole **10**. When the combustion front arrives at the injection borehole, continued injection of air drives the front back thru the stratum, feeding on the carbon residue left in the stratum during the first burn thru. Regulating the pressure of air in conduits **32** and **34**, utilizing higher pressure in conduit **34** than in conduit **32** and making these pressures substantially inversely proportional to the permeabilities of the layers has the effect of moving the combustion front thru the two layers at substantially the same rate.

The process described is applicable to the production of hydrocarbons from any gas permeable carbonaceous stratum containing layers of different permeability such as tar sand, Athabasca sand, lignite coal, etc.

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 carbonaceous stratum comprising a first layer of relatively high and a second layer of relatively low permeability separated by a relatively thin impermeable layer, which comprises separately packing off each said first and second layer in a section of an injection borehole therein; providing a separatae air injection conduit to each packed-off section; substantially simultaneously establishing in situ combustion in each said first and second layer; and driving the resulting combustion fronts thru said layers by separately injecting air to said layer of high permeability at a relatively low pressure and to said layer of low permeability at a relatively high pressure whereby the fronts move thru said stratum simultaneously at a more nearly uniform rate than would occur using the same injection pressure on each layer.

2. The process of claim 1 wherein in situ combustion is initiated in a production borehole spaced apart from said injection borehole and the combustion fronts are advanced countercurrently to the flow of air.

3. The process of claim 1 wherein the pressures are substantially inversely proportional to the permeabilities of said first and second layers.

4. The process of claim 1 wherein in situ combustion in initiated in an ignition borehole and the resulting combustion fronts are driven through the strata to an offset production borehole extending through the strata.

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