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INVERSE IN SITU COMBUSTION PROCESS

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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 borehole 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 front 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 overcome 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 selectively partially plugging the more permeable layers of a carbonaceous stratum by any suitable means thru an injection borehole in the stratum so that the different layers take injected air at more nearly uniform rates. The stratum is then ignited around an ignition or production borehole within easy air passage thru the stratum from the injection borehole and air is injected thru the injection borehole so that it passes thru the stratum to the resulting combustion zone thereby moving a combustion front thru the stratum to the injection borehole.

Usually a number of injection boreholes are utilized in a ring pattern around a production borehole where the combustion is initiated. In this type of pattern, the combustion front is moved outwardly thru the stratum in the form of an expanding ring toward the injection boreholes. In another type of operation, a line of ignition or production boreholes are flanked on either side by parallel lines of injection boreholes, combustion being initiated in the production boreholes and air being injected thru the two lines of injection boreholes so as to move the combustion front thru the stratum in both directions away from the production boreholes until it reaches the injection boreholes.

The process of this invention is applicable to any pattern of inverse in situ combustion, utilizing one or more air injection boreholes and one or more ignition or production boreholes where the combustion front is moved thru the stratum countercurrently to the flow of air. It is to be understood that where the term "air" is specified in this specification, oxygen-enriched air, substantially pure oxygen, or diluted air may be utilized, as long as the injected gas is combustion-supporting.

The more permeable layers in a carbonaceous stratum may be partially plugged in various ways. One method comprises injecting thru the injection borehole a fluid containing entrained particulate solids, whereby the more permeable layers take the injected fluid at a faster rate than the less permeable layers and more of the particulate solid. After a short injection period, the permeability of the several layers is more nearly equalized so that upon injection of air for supporting combustion and moving the combustion front thru the stratum, the combustion fronts in the different layers receive more nearly uniform air supply per square foot of front and the movement of the fronts in the different layers is at a more nearly uniform rate than would be accomplished without partial plugging.

Particulate solids which are applicable to the process include powdered rock, such as limestone; clay, such as bentonite or montmorillonite, and other aluminum silicates; and bauxite (alumina). Other materials include cellophane particles, mica flakes, particles of plastic of various types, such as polyolefins, and rubber. Any of the materials enumerated may be entrained in a fluid, either gaseous or liquid, and injected into the stratum thru the injection borehole. A preferred method comprises suspending or entraining the plugging material in air either outside of the borehole or within the borehole and injecting the gaseous entrainment into the walls of the injection borehole and thru the stratum.

It is also feasible to form a slurry of the particulate solid and inject the slurry, preferably aqueous, into the stratum. Care must be taken to not completely plug any of the layers of the stratum by utilizing an undue amount of solid in the slurry or suspension, or by inject-

ing for too long a period. The injection and partial plugging can be controlled by observing the injection pressure on a pressure gauge at the well head. After the partial plugging step, the plugging can be modified, if overdone, by treatment of the borehole wall with a liquid having dissolving power for the plugging agent, in the case of limestone, mild acid treatment will modify the permeability of the various layers.

Another method of partially plugging the more permeable layer or layers comprises subliming a solid material such as naphthalene, aluminum chloride, etc., into a hot gas by passing same over the solid material and injecting the resulting gas into the layer of stratum which is to be partially plugged. As the hot gas penetrates the stratum, it is cooled and the sublimed solid returns to solid form in a thin layer on the walls of the pores of the stratum thereby substantially reducing the permeability thereof. Any material which readily sublimes and returns to solid form upon cooling the ambient gas (containing the vaporized solid) is utilizable in the process.

According to another embodiment of the invention, one or more highly permeable layers are separately packed off and individually or collectively treated (if adjacent), in accordance with the partial plugging phase of the invention so as to decrease the effective permeability thereof in accordance with the permeability of less permeable layers in the stratum. After regulating the permeability of the packed off layer or layers, the packers are removed and air injection thru the entire stratum is effected in order to move the combustion front thru the various layers of the stratum from the ignition borehole therein.

When utilizing cellophane scrap, mica, plastic, or rubber for controlling the permeability of a layer, these materials also may be introduced into the injected air stream in the form of small flakes or plates which lodge in or against the wall of the borehole in proportion to the air flow thru each layer, thereby rendering the air flow thru the various layers more nearly uniform.

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. An in situ combustion process for producing hydrocarbons from a carbonaceous stratum composed of layers of varying permeability which comprises selectively partially plugging the more permeable layers in the wall of at least one air injection borehole thru said stratum so as to render the air injection rate more nearly uniform over the borehole wall; thereafter igniting the carbonaceous material around an ignition borehole spaced from said injection borehole in said stratum; and injecting air thru said injection borehole to force same thru said stratum to the resulting combustion front, thereby moving said front thru the layers of said stratum toward said injection borehole more nearly uniformly than would be effected without said plugging; and recovering hydrocarbons released from said stratum by the combustion thru said ignition borehole.

2. The process of claim 1 wherein said partial plugging comprises injecting a fluid containing entrained particulate solid into said stratum thru said injection borehole whereby the more permeable layers take injected fluid at a faster rate than the less permeable layers and more of said particulate solid.

3. The process of claim 2 wherein said particulate solid comprises powdered rock.

4. The process of claim 2 wherein said rock is limestone.

5. The process of claim 2 wherein said particulate solid comprises mica.

6. The process of claim 2 wherein said particulate solid comprises a plastic.

7. The process of claim 2 wherein said particulate solid comprises cellophane.

8. The process of claim 2 wherein said particulate solid comprises rubber.

9. The process of claim 1 wherein said partial plugging comprises subliming a solid into a hot entraining gas and injecting the resulting gas into said stratum thru said injection borehole whereby said gas cools and deposits said solid in the pores of said stratum.

10. The process of claim 1 wherein a more permeable layer is packed off and separately partially plugged prior to initiation of the combustion process.

11. The process of claim 10 wherein the partial plugging is effected by injecting an aqueous slurry of powdered limestone into the packed off layer.

12. A process for producing by in situ combustion a stratum composed of at least two carbonaceous layers of varying permeability penetrated by an injection borehole and an ignition borehole which comprises partially plugging the more permeable layer so as to render the permeabilities more nearly the same; thereafter igniting both layers around said ignition borehole spaced from said injection borehole; injecting combustion-supporting gas thru said layers from said injection borehole to said ignition borehole so as to move the resulting combustion fronts thru said layers toward said injection borehole at a more nearly uniform rate than would be effected without the partial plugging; and recovering hydrocarbons produced by the combustion thru the ignition borehole.

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