Dec. 7, 1965 M. PRATS 3,221,811

MOBILE IN-SITU HEATING OF FORMATIONS

Filed March 11, 1963 2 Sheets-Sheet 1

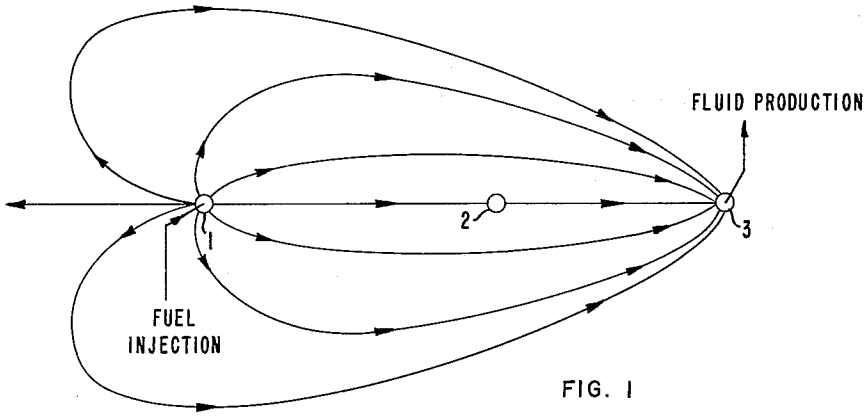


FIG. 1

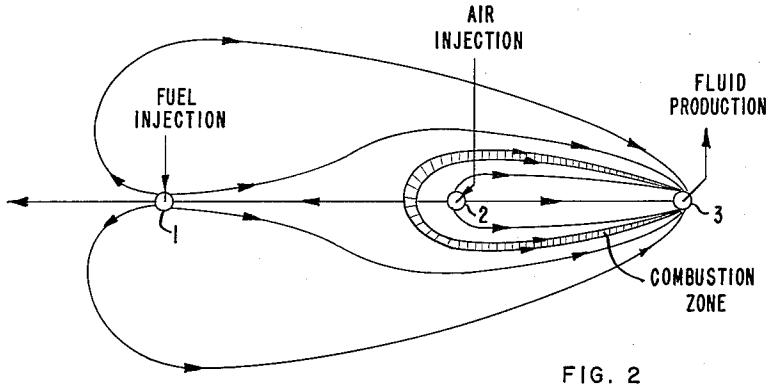


FIG. 2

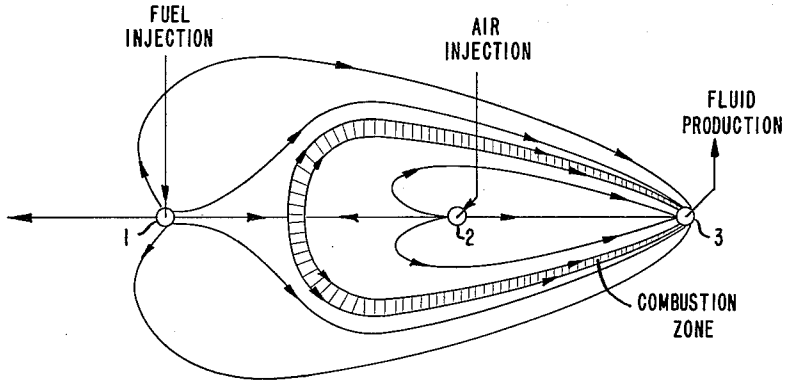


FIG. 3

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MOBILE IN-SITU HEATING OF FORMATIONS

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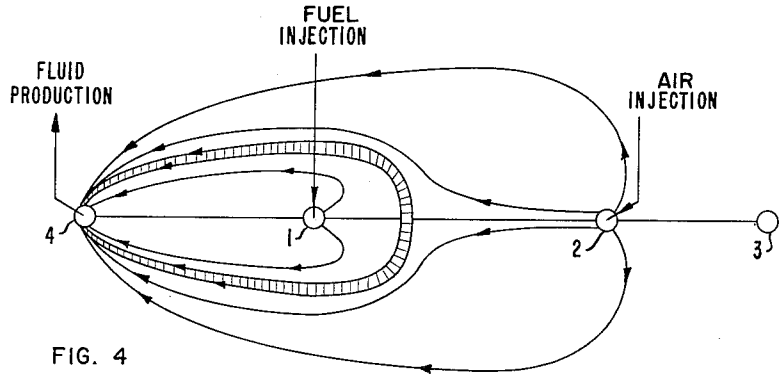


FIG. 4

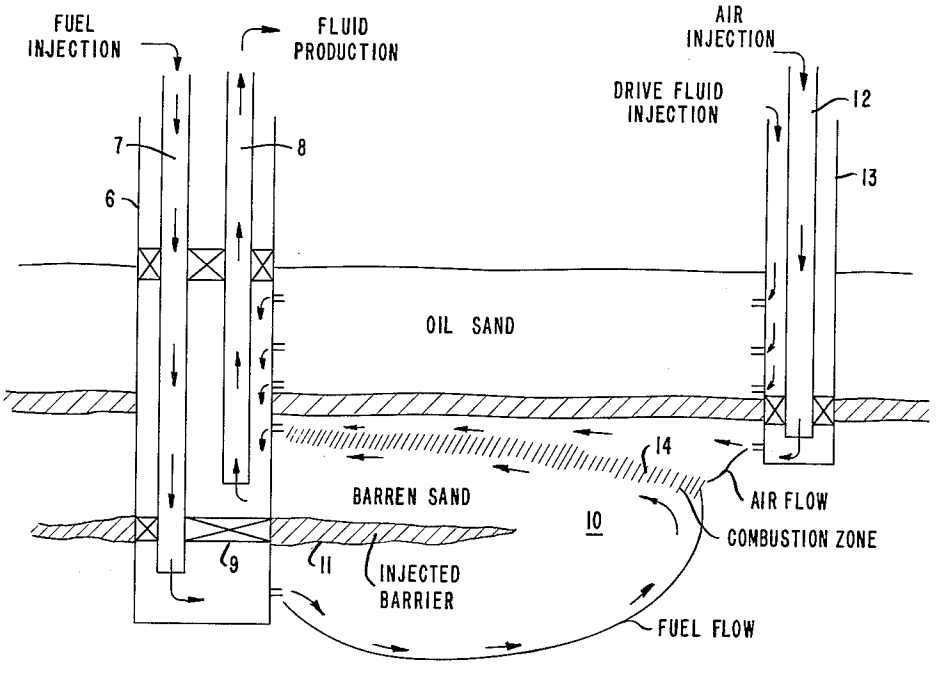


FIG. 5

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MOBILE IN-SITU HEATING OF FORMATIONS

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5 Claims. (Cl. 166—11)

This invention relates to the heating of hydrocarbon or oil-bearing formations and pertains more particularly to an in-situ method for thermally fluidizing minerals or hydrocarbons occurring in or near sub-surface formations in which combustion cannot be maintained by the injection of air alone. The present method is especially useful in producing material from formations containing hydrocarbons or other organic materials, such as coal, in quantities that are not sufficient for combustion to be maintained in the formation by the injection of air or another oxygen-containing fluid.

The present method is based on the steps of injecting a fuel-containing fluid at one location, injecting an oxygen-containing fluid at a different location, burning the mixture formed where the fluids meet within the formation, and producing the combustion products, and displaced fluids from a third location. By adjusting the injection rates, the zone of combustion can be maintained in or moved through selected regions within the formation.

Combustion within a formation requires the presence of a fuel and oxygen in critical proportions at a temperature above a critical minimum. Some formations in which combustion cannot be maintained by the injection of air contain combustible materials or contain substances which produce combustible materials when they are heated, but contain these substances in proportions such that the heat from burning the combustible materials is insufficient, or is too rapidly lost, to maintain a temperature at which ignition occurs.

In oil production processes, especially in the secondary recovery of oil, it is sometimes desirable to move a combustion front through a substantially barren formation, that is, one which will not support combustion, in order to supply heat to an adjacent formation. Various patents disclose methods of supplying both air and fuel to maintain an in-situ combustion in such barren formations.

However, in each of the processes suggested in the patent literature, the fuel and air are injected through the same well, either concurrently as components of a single fluid stream, or sequentially as components of intermittently injected fluids. One drawback to such a procedure is that when combustible materials flowing from the same injection well reach their ignition temperature within a cavern or fissure near the injection well, a backflashing can occur. This may damage the well. Secondly, in the patented procedures the pattern of the burning zone is necessarily confined to the general shape of an arc of a circle around the injection well and the region through which the burning zone can be moved is necessarily a generally circular or spherical region of expansion around the injection well.

It is therefore a primary object of the present invention to provide a method of carrying out in-situ heating within a formation to thermally fluidize minerals or hydrocarbons occurring in a formation which does not contain enough fuel to support combustion.

A further object of the present invention is to provide a method of heating an underground formation by forming a combustion front therein at any desired point so as to heat a selected region of the formation.

Another object of the present invention is to provide a method of heating an underground formation by means

of a combustion front formed therein and subsequently selectively moving the combustion front as desired within the formation to heat various regions of the formation so as to volatilize minerals contained within the formation or to volatilize or reduce the viscosity of hydrocarbon materials contained within the formation and move them to a production well.

Still another object of the present invention is to provide a method for producing minerals or hydrocarbons from an underground formation by selectively heating various regions of the formation one or more times by means of a moving combustion front which is moved either continuously or in a stepwise fashion through the formation.

These and other objects of the invention will be understood from the following description taken with reference to the drawing, wherein:

FIGURES 1 through 4 are plan views of three wells with various flow patterns of injected materials being schematically shown extending between the wells; and,

FIGURE 5 is a diagrammatic view of a pair of wells taken in longitudinal cross-section with the air and fuel flow patterns being schematically shown between the wells.

In FIGURE 1 a planned view of the preferred arrangements of wells is shown for use in carrying out the method of the present invention. The method is started by injecting a fuel such as methane into the formation to be heated through well number 1 and producing the fluid at well number 3. The several lines forming flow patterns of fuel represent the injection of fuel at successive and increasing flow rates.

After a suitable pattern of flow of fuel from well 1 to well 3 has been established, air or an oxygen-containing fluid is injected through well 2 (FIGURE 2) either simultaneously with or subsequent to the formation temperature of well 2 being raised by means of a suitable down-hole heating device. Alternatively, at the time the air is injected into well 2 with the fuel being present in the adjacent formation, the mixture can be ignited by any suitable ignition procedure, e.g., by utilizing an ignition means which would be lowered into the well to the desired depth. The air injection rate is preferably kept small enough compared to the fuel injection rate so that the fluids produced in well 3 do not constitute an explosive mixture. With a small air injection rate, the regions of contact of the fuel and air are at least partially within the zone of the formation heated by any down-hole heater used within well 2. Once ignition has been accomplished, the heater can be turned off and the heat of combustion used to maintain the temperature of the air and fuel above the ignition temperature. The hatched portion shown in FIGURE 2 represents schematically the combustion front surrounding well 2 and extending to well 3.

The location of the combustion front (hatched portion) within the formation can be readily changed by adjusting the air and fuel injection rates. Increasing the injection rate of the air relative to that of the fuel moves the combustion zone further away from well 2, both in the direction toward well 1 and in the direction normal to a line between wells 1 and 2. A reduction in the fuel injection rate into well 1 will cause the combustion zone to move still further from well 2. An increase in the fuel injection rate into well 1 would have the opposite effect. Simultaneous increase of injection rates of both the fuel into well 1 and the air into well 2 would cause a greater sideward movement of the combustion front, thus allowing the combustion front to sweep into greater areas of the formation under consideration.

An analysis of the produced gas from well 3 indicates

whether combustion is occurring. In the event that combustion within the formation has stopped, the gaseous mixture in the formation can be re-ignited in the manner in which it was originally ignited. The location of the regions in which combustion is occurring within the formation can be determined by methods well-known to reservoir engineers, such as by calculating the flow paths of the injected gas. Combustion can be maintained within the formation while moving the combustion front from one region to another as long as the injection rates of the fuel and the air are not changed so rapidly that the mixing zone is moved into portions of the formation which have not been previously heated to ignition temperature by the combustion front.

As illustrated in FIGURE 4, the location of the burning region within the formation can be readily changed by producing the fluids from an additional well **4** for example. By producing from well **4** located to the left of well **1**, the burning region (hatched zone) can be relocated in a manner shown. The combustion zone can be moved back and forth between the wells as many times as desired. The rate at which the combustion zone can be moved is materially greater than the rates of movement which are possible for combustion zones produced by burning in a matrix containing a static body of fuel.

While the method of the present invention has been described herein above as being carried out through three wells or conduits in communication between the surface and the underground formation to be heated, it is quite apparent that it is not essential that three sub-surface locations be employed, as shown in FIGURE 5. In the arrangement shown in FIGURE 5, the well **6** is provided with 2 conduits **7** and **8** through which fuel is injected, and oil or other fluid production is produced, respectively. The open lower ends of the two conduits **7** and **8** are isolated one from the other by means of a packer **9**. Preferably prior to start of production the barren sand formation **10** has been fractured in a manner well-known to the art with a barrier **11** preferably of a heat-resistent material such as cement, being injected into the fracture so as to extend radially from the well **4**. Alternately, the barrier of a sealing material could be injected without fracturing the formation. From the fuel flow lines drawn on FIGURE 5 it will be seen that the injected barrier directs the fuel flow into the formation in a manner such as to cause it to sweep a considerable area prior to it being contacted by the flow of air from conduit **12** positioned in well **13**. Thus a combustion front forms at **14** and may be moved up or down within the formation by varying the flow of the two injected fluids. In the arrangement shown in FIGURE 5, two of the three sub-surface locations are provided in a single well.

The method in general comprises establishing fluid communication from points above the surface to a least three sub-surface locations, establishing fluid communication through the formation between the sub-surface locations, injecting a fuel-containing fluid into the formation around at least one of the sub-surface locations, injecting an oxygen-containing fluid into the formation around at least one of the sub-surface locations, adjusting the relative rates of the injections so that the injected fluids meet within the formation and displace fluids into the vicinity of at least one of the sub-surface locations, igniting the mixture formed along the junction of the injected fluids, controlling the relative rates of injection so that the burning mixture extends along a path having a selected and movable portion within the formation, and withdrawing the fluids displaced in the vicinity of at least one of the sub-surface locations.

The above-described formation heating method can be used in conjunction with an oil production operation by advancing the burning mixture within a formation adjacent to an oil-bearing formation to decrease thermally the viscosity of the oil being produced, for example, by the conventional type of fluid drive operation. It can be similarly used in conjunction with the production of any mineral matter capable of being thermally converted to a liquid or gaseous fluid, for example, viscous petroleum materials. In addition to hydrocarbons, various examples of volatilizable contents of sedimentary strata susceptible to the method of the present invention may be native metals such as mercury, bismuth, antimony, arsenic, zinc, etc., sulfur, both native and in composition, inpyrite, mispickel, galena, redruthite, argentite, blends, etc., chlorides of the metals and alkalis such as calomel, sylvite, chlorite, salmiac, etc., oxides of the metals, such as arsenolite, etc., sulfides of the metals, such as cinnabar, etc., inorganic acids in compositions, such as carbonic dioxide, etc., and any volatilizable minerals produced by the chemical action upon the constituents of the strata of mineralizing agents.

The process can be used either for heating or for simultaneously thermally fluidizing and fluid driving a material which is present in the formation in which in-situ combustion cannot be maintained by injecting air along.

In simultaneously thermally fluidizing, fluid driving, and producing a material, the location into which fluids are displaced is maintained at a pressure lower than the injection pressures of the fuel in the air, and the fluidized material is withdrawn along with the fluid combustion products and the fluids displaced from the formation.

The initial permeability of the formation in which the burning is to be conducted is not a limitation. The necessary fluid communication through the formation can be established by hydraulic fracturing, underground explosions, or the like. The fissures and caverns in locations in which the fuel-containing and oxygen-containing fluids meet will become filled with explosive mixtures and detonations will occur. Such explosions will convert the nearby portions of the formation to highly porous fragmented portions and the region of this occurrence will be moved along with any movements of the junction of the fuel-containing and oxygen-containing fluids.

In an operation which a normally solid material is thermally liquified and the fluid driven into a production well, the liquified material, such as sulfur, must be pumped out or removed in a manner so as to maintain a relatively low pressure in the production well. The present method can be employed to roast an ore, to reduce the viscosity of a liquid or solid which cannot be fluid-driven at the applicable pressures, or to pyrolyze a material into fluid products.

I claim as my invention:

1. A method of heating extensive areas of an underground formation for the purpose of heating a material in an underground location, said method comprising the steps of

(a) injecting fuel at one point into an underground formation which is deficient in combustible material in an amount sufficient to maintain an underground combustion,

(b) injecting an oxygen-containing fluid into said underground formation at a point spaced from said fuel-injection point but within contact range of said injected fuel,

(c) igniting said mixture of fuel and oxygen-containing fluid at least at one point along the contact front in the formation between said injection points where the fuel and oxygen-containing fluid combine into a combustible mixture, thereby forming a combustion front which subsequently propagates along the entire contact front,

(d) discharging the products of said combustion from said formation at a point displaced from the points at which the fuel and the oxygen-containing fuel are separately injected,

(e) controlling the injection rates of said fuel and said oxygen-containing fluid to maintain the combustion front in a selected area of said formation being heated, and

(f) slowly increasing the flow rate of one of said injected materials relative to the other to cause the combustion front to move from a portion of the formation closer to one injection point toward the other injection point.

2. The method of claim 1 including the step of slowly decreasing the flow rate of said one injected material to cause the combustion front to move in the opposite direction between said injection points.

3. The method of claim 1 wherein the injection of fuel and the injection of oxygen-containing fluid into the formation take place through separate wells at points spaced from each other and from a production well.

4. The method of claim 3 wherein the injection wells are both to one side of and substantially in line together with said production well.

5. The method of claim 1 wherein the steps of injecting fuel and of injecting oxygen-containing fluid take place through separate spaced apart injection wells while the products of combustion are first discharged through a production well to one side of the injection wells and including the steps of subsequently closing the production well and opening another production well through which the products may be discharged substantially on the opposite side of said injection wells.

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