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2

3,209,822 RECOVERY OF PETROLEUM BY DIRECT IN-SITU COMBUSTION

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This invention relates to the recovery of hydrocarbons from a subterranean formation and relates more particularly to an improvement in the in-situ combustion process for recovery of hydrocarbons from a subterranean formation.

Various methods have been proposed for recovering hydrocarbons from subterranean formations containing hydrocarbon materials. One of these methods involves combustion of a portion of the hydrocarbon material in the formation to effect heating of the formation, the combustion being supported by passage of an oxidizing gas through the formation. Upon this heating of the formation, the hydrocarbon material in the formation is converted chemically and physically and thereby flows more readily from the formation into a well from which it may be removed. In the direct drive combustion method, the oxidizing gas, which ordinarily is air, is injected into the formation containing the hydrocarbon material through an input well leading to the formation from the surface of the earth. Combustion is initiated within the formation at the input well and with continued injection of the air, a combustion front moves from the input well through the formation in the direction of the output well. As the combustion front moves through the formation, hydrocarbons are displaced from the formation and migrate in advance of the combustion front to the production well. The formation in advance of the migrating combustion front is progressively cooler with distance from the combustion front with the coolest portion of the formation being at the production well. As the hydrocarbons displaced from the formation migrate in advance of the combustion front, they become cooled upon passing through the cooler portions of the formation. Thus, the hydrocarbons condense, or, where originally in the liquid phase, increase in viscosity. As a result, a liquid bank is created within the formation in advance of the combustion front. This liquid bank can block the flow of the air between the input well and the output well and where it occurs in the vicinity of the production well can block the flow of air sufficiently to effect cessation of combustion.

It is an object of this invention to improve the recovery of hydrocarbons by the in-situ combustion process from a subterranean formation.

It is a more specific object of this invention to minimize the blocking effect to the flow of air of a liquid bank in a subterranean formation undergoing in-situ combustion.

It is another object of this invention to increase the mobility of hydrocarbon material in the vicinity of the production well of a subterranean formation undergoing in-situ combustion.

In accordance with the invention, there is provided a procedure which involves as a first step passing an oxidizing gas into a subterranean formation containing hydrocarbon material through a first well leading thereto from the surface of the earth. Subsequently, as another step of the procedure, oxidizing gas is passed through the same formation to the first well through a second well leading thereto from the surface of the earth. Combustion of the hydrocarbon material within the formation is initiated at the second well, and the oxidizing gas is continued to be passed into the formation through this second

well at which ignition was effected. As a result, a combustion front advances through the formation from the second well in the direction of the first well. The hydrocarbons displaced from the formation as a result of the migration of the combustion front are recovered from the first well.

The first step of the procedure is based upon the observation that passage of an oxidizing gas through a subterranean formation containing hydrocarbon material can effect auto-oxidation of the hydrocarbon material within the formation. This autooxidation occurs at a relatively low rate and the exothermic heat of reaction is consequently released slowly. However, with continued passage of the oxidizing gas into the formation, the auto-oxidation occurs to a significant extent to effect appreciable increase in the temperature of the formation. Moreover, the rate at which the auto-oxidation occurs progressively increases with increase in the temperature of the formation. Accordingly, the rate of increase in the temperature of the formation with continued passage of the oxidizing gas becomes progressively greater with time. Eventually, in fact, the temperature attained within the formation can be the ignition temperature of the hydrocarbon material within the formation. Thus, in consequence of the first step of the procedure of the invention, the temperature of the formation inwardly from the well into which the oxidizing gas is passed can be increased to a desired extent.

In the practice of the invention, the oxidizing gas is passed into the formation for such time that a desired temperature is effected within the formation in the vicinity of the well through which the oxidizing gas is passed. Ordinarily, a subterranean formation in which the in-situ combustion process is to be applied will have a temperature between about 70° and 100° F. However, such formations may have temperatures less than 70° F. and higher than 100° F. Passage of oxidizing gas into the formation is carried out to the point that the temperature attained within the formation is sufficiently high to prevent substantial condensation of the vaporized hydrocarbons and substantial increase in viscosity of the liquid hydrocarbons displaced by the combustion front in the second step of the procedure. This temperature will depend upon the type of hydrocarbon material in the formation. However, satisfactory results are obtained where the formation in the vicinity of the well through which the oxidizing gas is passed is heated to a temperature between about 500° and about 600° F. On the other hand, it is desirable to limit the extent to which the oxidizing gas is passed into the formation to avoid the attainment of temperatures that would effect coking of the hydrocarbon material within the formation. At temperatures at which combustion will occur, the hydrocarbon material in the formation is cracked or coked and the coke reduces to some extent the permeability of the formation. Coking of the hydrocarbon material can occur in the formation at temperatures above about 500° and 600° F. However, the temperature of coking will depend upon the chemical and physical characteristics of the hydrocarbon material within the formation. In any case, the temperature at which coking of the hydrocarbon material will occur, and thus the maximum temperature to be attained within the formation in the vicinity of the well through which the oxidizing gas is passed in the first step of the procedure, can be determined by subjecting a sample from the formation to increasing temperature and noting the temperature at which coking of the hydrocarbon material occurs.

It is preferred that passage of the oxidizing gas be continued until the formation has been heated to the desired temperature for at least 5 percent of the distance between the well into which the oxidizing gas is passed and the well where initiation of combustion is to take place. The

greater this distance, of course, the greater will be the effect of the passage of the oxidizing gas in minimizing the blocking effect of a liquid bank formed during the in-situ combustion operation. As is known, the mobility of the hydrocarbons in the immediate vicinity of the production well is of greater importance from the standpoint of rate of production than the mobility elsewhere in the formation. Stated otherwise, a liquid bank created around the immediate vicinity of the production well effects a greater decrease of production than the same liquid bank created at another point in the formation. Accordingly, from a practical standpoint, satisfactory results can be obtained by passage of oxidizing gas into the formation until the desired temperature is attained within the vicinity of the well. On the other hand, passage of the oxidizing gas may be continued until the formation has been heated to the desired temperature for any distance between the two wells. This distance may be 25 percent, 50 percent, or greater.

Passage of the oxidizing gas in the first step of the procedure of the invention may be continuous or may be intermittent. Following attainment of the desired temperature within the formation for the desired distance by passage of the oxidizing gas, the passage of the oxidizing gas through the well is discontinued. Initiation of combustion is then effected at the second well. For initiation of combustion, any of the conventional procedures for this purpose may be employed. Thereafter, oxidizing gas is passed into the formation through the second well to effect the migration of the combustion front through the formation in the direction of the first well. By reason of the heating of the formation by passage of the oxidizing gas in the first step of the procedure of the invention, the blocking effect of condensation of hydrocarbons as they migrate in advance of the combustion front in the direction of the first well is reduced. Additionally, the effect of the liquid hydrocarbons increasing in viscosity as they migrate in the direction of the first well is also reduced. Thus, passage of the oxidizing gas to effect migration of the combustion front can be maintained at a desired rate without excessive increase in the pressure of injection or cessation of combustion.

With continued passage of the oxidizing gas into the second well and advance of the combustion front through the formation, hydrocarbons migrate to the first well. The hydrocarbons enters the first well and are removed from the well. Removal of the hydrocarbons displaced by in-situ combustion is known in the art and any desired procedure for this purpose may be employed.

The oxidizing gas employed in the first and second steps of the procedure of the invention will ordinarily be air. However, if desired, other oxidizing gases may be employed. For example, oxygen may be employed. Further, oxygen-enriched air may also be employed. Air containing flue gas or other gas to reduce the amount of oxygen may also be employed.

The procedure of the invention may be carried out in any type of subterranean formation containing hydrocarbon material or a material providing a source of hydrocarbons. Thus, the procedure may be carried out in a formation containing petroleum, in an oil shale formation, or in a tar sand formation. Further, the formation may be preliminarily treated, if desired or necessary, for the purposes of establishing, or increasing permeability. Thus, for example, the formation preliminarily may be acidized or may be fractured.

Whereas the procedure of the invention reduces the effects due to condensation of vaporized hydrocarbon material and increase in viscosity of liquid hydrocarbon material, this desirable result is achieved without the necessity of employing equipment other than that ordinarily employed in the in-situ combustion operation. Thus, passage of the oxidizing gas into the formation in the first step of the procedure may be effected employing the same equipment subsequently employed for passage of the ox-

dizing gas into the formation in the second step for advance of the combustion front. Accordingly, the desired results of the invention can be obtained without cost for additional equipment.

Having thus described my invention, it will be understood that such description has been given by way of illustration and example and not by way of limitation, reference for the latter purpose being had to the appended claims.

I claim:

1. In a procedure for recovering hydrocarbons from a subterranean formation containing hydrocarbon material wherein a combustion front is initiated within said formation at an input well, oxidizing gas is passed into said formation at an input well, oxidizing gas is passed into said formation through said input well, and said combustion front is advanced through said formation from said input well to an output well, the process comprising:

(a) passing through said output well into said formation prior to initiation of said combustion front an oxidizing gas, and

(b) continuing passage of said oxidizing gas through said output well into said input well until the temperature of said formation in the vicinity of said output well has been increased by auto-oxidation of said hydrocarbon material insufficiently high to cause coking of said hydrocarbon material but sufficiently high to reduce the blocking effect on flow of oxidizing gas of condensation of vaporized hydrocarbons and of increase in viscosity of liquid hydrocarbons displaced from said formation by said combustion front.

2. The procedure of claim 1 wherein said oxidizing gas is passed into said formation through said output well until said formation in the vicinity of said output well is heated by auto-oxidation for a distance of at least 5 percent between said output well and said input well.

3. The procedure of claim 1 wherein said oxidizing gas is passed into said formation through said output well until said formation in the vicinity of said output well is heated to temperature between about 500° F. and about 600° F.

4. The procedure of claim 1 wherein said oxidizing gas is passed into said formation through said output well until said formation is heated by auto-oxidation for a distance of at least 5 percent between said output well and said input well to a temperature between about 500° F. and about 600° F.

5. The procedure of claim 1 wherein said oxidizing gas is passed intermittently through said output well into said formation.

6. A procedure for recovering hydrocarbons from a subterranean formation containing hydrocarbon material and penetrated by an input well and an output well, comprising:

(a) passing into said formation through said output well an oxidizing gas to effect increase in the temperature of said formation in the vicinity of said output well by auto-oxidation of hydrocarbon material in said formation insufficiently high to cause coking of said hydrocarbon material but sufficiently high to effect increase in the temperature of said formation in the vicinity of said output well to reduce the blocking effect on flow of oxidizing gas of condensation of vaporized hydrocarbons and of increase in the viscosity of liquid hydrocarbons displaced from said formation by a migrating combustion front,

(b) thereafter discontinuing passage of said oxidizing gas into said formation through said output well,

(c) effecting initiation of combustion of hydrocarbon material in said formation at said input well to form a combustion front in said formation,

(d) passing into said formation through said input well an oxidizing gas to effect migration of said combustion front through said formation in the direction of said output well, and

5

(e) recovering hydrocarbon material displaced from said formation by said combustion front from said output well.

7. The procedure of claim 6 wherein said oxidizing gas is passed into said formation through said output well until said formation in the vicinity of said output well is heated by auto-oxidation for a distance of at least 5 percent between said output well and said input well.

8. The procedure of claim 6 wherein said oxidizing gas is passed into said formation through said output well until said formation in the vicinity of said output well is heated by auto-oxidation to a temperature between about 500° F. and about 600° F.

9. The procedure of claim 6 wherein said oxidizing gas is passed into said formation through said output well until said formation is heated by auto-oxidation for

6

a distance of at least 5 percent between said output well and said input well to a temperature between about 500° F. and about 600° F.

10. The procedure of claim 6 wherein said oxidizing gas is passed intermittently into said formation through said output well.

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