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METHOD OF HEATING A SUBTERRANEAN RESERVOIR CONTAINING HYDROCARBON MATERIAL

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This invention relates to the recovery of hydrocarbons from a subterranean formation containing hydrocarbon material and relates more particularly to the recovery of such hydrocarbons by a procedure involving heating of the formation.

Various methods involving heating have been proposed for the recovery of hydrocarbons from subterranean formations containing a hydrocarbon material. With heating of the hydrocarbon material within the formation, the viscosity of the material is reduced or the chemical composition of the material is changed to form a material which has a lower viscosity. In either case, the hydrocarbon material in the formation is able to flow more readily through the formation and its recovery from a production, or output, well is thereby facilitated. One of these methods involves the combustion of a portion of the hydrocarbon material within the formation. In this method, an oxidizing gas is passed into the formation through an input, or injection, well and the hydrocarbon material within the formation is ignited by suitable means. The zone of combustion, or combustion front, produced by ignition migrates through the formation and the hydrocarbons released from the formation by the migrating combustion front are driven through the formation into the direction of the output well. The hydrocarbons enter the output well and they are removed therefrom and brought to the surface of the earth. While this method, termed the in-situ combustion method, is satisfactory from the standpoint of the results desired, it is subject to certain drawbacks. Primarily, the in-situ combustion method suffers from the drawback that an appreciable portion of the hydrocarbon material in the formation is consumed by the migrating combustion front with consequent decrease in the proportion of hydrocarbons that can be recovered. Associated therewith is the drawback that the excessively high temperatures attained by combustion of the hydrocarbon material require close control of the operation in order to avoid damage or destruction to equipment in both the input and output wells. Methods of effecting heating in the formation other than by in-situ combustion are also available. For example, fluid heated at the surface of the earth can be passed into the formation through an input well. However, these methods suffer from the drawback that they require the utilization of a fuel, with concomitant expense, to heat the fluid passed into the formation.

It is an object of this invention to provide a method for heating a subterranean formation containing hydrocarbon material for recovery of hydrocarbons from the formation.

It is another object of this invention to reduce the cost of heating a subterranean formation containing hydrocarbon material.

It is another object of this invention to avoid excessive heating of wells penetrating a subterranean formation con-

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taining hydrocarbon material for recovery of hydrocarbons from the formation.

It is another object of this invention to recover hydrocarbons from a subterranean formation by a low temperature heating procedure.

It is another object of this invention to increase the proportion of hydrocarbons recovered from a subterranean formation by a heating procedure which does not require the passage of a previously heated fluid through the formation.

These and further objects of the invention will become apparent from the following detailed description.

In accordance with the invention, there is provided a procedure which involves as its essential steps passing an oxidizing gas first in one direction and thereafter in substantially the opposite direction through a subterranean formation containing hydrocarbon material to effect auto-oxidation of the hydrocarbon material and thereby heat the hydrocarbon material within the formation. The heated hydrocarbon material is then recovered from the formation through an output well. In a specific embodiment, the procedure includes a first step of passing an oxidizing gas through the subterranean formation from a first well to a second well. Passage of the oxidizing gas is continued through the formation from the first well to the second well until the temperature within the formation begins to approach the ignition temperature of the hydrocarbon material as indicated by the carbon dioxide content of the effluent gas from the formation to the second well. At this time, passage of the oxidizing gas from the first well to the second well is discontinued. The procedure includes, thereafter, a second step of passing an oxidizing gas through the formation. However, in this step, the oxidizing gas is passed through the formation from the second well to the first well. Thereafter, passage of the oxidizing gas is continued until the temperature within the formation again approaches the ignition temperature of the hydrocarbon material as indicated by the carbon dioxide content of the effluent gas from the formation to the first well. Again, at this time, passage of the oxidizing gas is discontinued. As a final step, an inert driving fluid is passed through the formation to drive the heated fluid hydrocarbons from the formation to an output well from which they may be recovered.

It has been observed that the passage of an oxidizing gas through a subterranean formation containing hydrocarbon material can effect auto-oxidation of the hydrocarbon material within the formation. This auto-oxidation occurs at a relatively low rate and the exothermic heat of reaction is consequently released slowly. However, with prolonged passage of the oxidizing gas through the formation, the auto-oxidation occurs to a significant extent and effects 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 prolonged passage of the oxidizing gas becomes progressively greater with time. Thus, in consequence of the passage of the oxidizing gas through the formation, the average temperature of the formation between the well from which the oxidizing gas enters the formation, or input well, and the well from which the oxidizing gas leaves the formation, or output well, can be increased to a desired extent.

As a result of the auto-oxidation, the temperature attained within the formation can be the ignition temperature of the hydrocarbon material within the formation. In accordance with the invention, passage of the oxidizing gas through the formation between the input well and the output well is discontinued when the temperature within the formation begins to approach the ignition temperature of the hydrocarbon material within the formation. Attainment of temperatures approaching the ignition temperature of the hydrocarbon material is indicated by the carbon dioxide content of the effluent gas from the formation to the output well.

As the oxidizing medium passes through the formation from the input well to the output well and auto-oxidation of the hydrocarbon material occurs, carbon dioxide is produced. Concomitantly with the production of carbon dioxide, the oxygen content of the oxidizing gas is decreased. Accordingly, a measure of the rate at which oxidation of the hydrocarbon material within the formation is occurring is the carbon dioxide content, or the oxygen content, of the effluent gas from the formation to the output well. As stated previously, the rate at which the auto-oxidation occurs increases with increase in the temperature of the formation. Thus, the rate of auto-oxidation is also a measure of the temperature of the formation. When the carbon dioxide content of the effluent gas from the formation to the output well exceeds about 3 percent by volume, the temperature of the hydrocarbon material is beginning to approach the ignition temperature. It is at this point that passage of the oxidizing gas through the formation from the input well to the output well is discontinued.

Determination of the carbon dioxide content of the effluent gas may be by any desired means. For example, the effluent gas may be analyzed for its carbon dioxide content by employing an Orsat apparatus. Analysis may also be made employing apparatus that detects changes in the physical properties of the effluent gas with changes in the carbon dioxide content. Additionally, analysis may be made continuously or intermittently.

As a next step in the procedure of the invention, oxidizing gas is passed through the formation in a direction substantially opposite to that in the first step of passage of the oxidizing gas. Most conveniently, passage of the oxidizing gas in the opposite direction can be accomplished by passing the oxidizing gas from the well previously used as the output well. However, if desired, the oxidizing gas may be passed into a different input well and the effluent gas recovered from an output well located within the formation on a line substantially parallel to the line on which the first input and output wells were located. This latter output well may be the well employed as the input well in the first step of passing oxidizing gas through the formation or may be another well. Passage of the oxidizing gas in this second step is maintained to effect auto-oxidation of the hydrocarbon material in the formation until the temperature of the hydrocarbon material begins to approach the ignition temperature as indicated by the carbon dioxide content of the effluent gas from the output well exceeding about 3 percent by volume.

In the first step of passing the oxidizing gas through the formation, the heating of the formation will occur to a greater degree in the neighborhood of the input well than in the neighborhood of the output well. The oxygen content of the oxidizing gas passing through the formation will be at a maximum at the input well and at a minimum at the output well. Accordingly, the auto-oxidation will be at a maximum at the input well and decrease with distance through the formation from the input well to the output well. In the second step of passing the oxidizing gas through the formation, the oxidizing gas will contain the higher proportion of oxygen in that portion of the formation where the oxidizing gas

previously contained the lower proportion of oxygen. Also, the oxidizing gas will contain the lower proportion of oxygen in that portion of the formation where the oxidizing gas previously contained the higher proportion. As a result, these portions of the formation heated to the least extent in the first step of passing the oxidizing gas through the formation are heated to the greatest extent in the second step of passing the oxidizing gas through the formation. As a result, a more uniform heating between the wells is attained. Either or both of the first and second steps of passing the oxidizing gas through the formation may be repeated. Either or both of these steps, further, may be repeated as often as desired. With each repetition of either of the two steps, the temperature distribution within the formation becomes more uniform. Thus, repetition may be effected until a desired temperature distribution is attained.

In the steps of passing the oxidizing gas through the formation, it is preferred that the oxidizing gas be passed into the formation from the input well at an elevated pressure. For some hydrocarbon materials, at least, the rate of auto-oxidation at lower pressures of the oxidizing gas is directly proportional to the pressure of the oxygen. At higher pressures, however, the rate of auto-oxidation is practically independent of the pressure of the oxygen. Thus, the oxidizing gas is preferably passed into the formation at a pressure of at least 8 atmospheres to take advantage of the reduced dependence of the oxygen pressure on the rate of auto-oxidation.

The oxidizing gas employed may be any gas containing oxygen. Preferably, air is employed. However, if desired, other oxidizing gases may be employed. For example, oxygen may be employed. Further, oxygen enriched air may be employed. If desired, an inert fluid may be added to air to reduce the amount of oxygen therein and this gas may be employed for auto-oxidation. For example, flue gas may be added to the air. However, the use of air containing an inert fluid will decrease the proportion, or pressure, of the oxygen in the air and thus decrease the rate of auto-oxidation with consequent increase in the time required for heating of the formation.

Following heating of the formation, inert driving fluid is passed through the formation to drive the heated hydrocarbons from the formation to an output well. Water may be used as the inert driving fluid. This output well may be the same output well employed in the second step of passing the oxidizing gas through the formation. On the other hand, it may be the well employed as an output well in the first step of passing oxidizing gas through the formation. On the other hand, another output well may be employed. The input well for the inert fluid may be the input well employed in the second step of passing oxidizing gas through the formation or may be another input well.

The procedure of the invention can be employed in connection with the use of a single input well and a single output well in the steps of passing the oxidizing gas through the formation. However, a plurality of input wells or a plurality of output wells may be employed in either or both the steps of passing oxidizing gas through the formation. Thus, for example, the procedure of the invention may be employed in connection with a 5-spot pattern. In this pattern, four wells located in the corners of the square can be employed as the output wells and a well located centrally of these four output wells can be employed as an input well. The second step of passing the oxidizing gas through the formation may be effected by employing the wells located at the corners of the square as input wells and the well located centrally of these wells as the output well. Additionally, a line of input wells may be employed along with a line of output wells. It is also possible to employ a single

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well in which the oxidizing gas is passed into the formation at one height and the effluent gas is removed from the formation at another height. Any other conventional well pattern 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 purpose of establishing, or increasing, permeability. Thus, for example, the formation preliminarily may be acidized or may be fractured.

By the procedure of the invention, recovery of hydrocarbons is effected without excessive heating of the formation. While some hydrocarbon material is consumed as a result of the auto-oxidation, the amount thus consumed is insignificant. Further, heating is effected without the necessity of utilizing a fuel to heat a fluid medium to be passed into the formation. Moreover, the temperatures attained within the formation are well below those that would damage or destroy equipment in the input or output wells.

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. A procedure for recovering hydrocarbons from a subterranean formation containing hydrocarbon material comprising:

passing an oxidizing gas from an input well means to output well means through said formation in a first direction to effect auto-oxidation of said hydrocarbon material only until the temperature within the formation traversed by the oxidizing gas passed from said input well means begins to approach the ignition temperature of the hydrocarbon material, and

thereafter passing an oxidizing gas from an input well means to output well means through said formation traversed in said first passage of oxidizing gas in a direction substantially opposite to said first direction to effect auto-oxidation of said hydrocarbon material only until the temperature within the formation traversed by the oxidizing gas passed from said last-mentioned input well means begins to approach the ignition temperature of the hydrocarbon material and thereby heat said hydrocarbon material in said formation, and

thereafter recovering heated hydrocarbons from said formation through an output well means.

2. A procedure for recovering hydrocarbons from a subterranean formation containing hydrocarbon material comprising:

as one step passing an oxidizing gas through said formation from an input well to an output well to effect auto-oxidation of said hydrocarbon material and thereby heat said hydrocarbon material,

discontinuing passage of said oxidizing gas through said formation when the temperature within said formation traversed by the oxidizing gas passed from said input well begins to approach the ignition temperature of said hydrocarbon material,

as another step passing oxidizing gas through said formation traversed in said first passage of oxidizing gas from an input well to an output well in a direction through said formation substantially opposite to the direction of said oxidizing gas in said first passage of said oxidizing gas through said formation to effect auto-oxidation of said hydrocarbon material and thereby heat said hydrocarbon material, thereafter

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discontinuing passage of said oxidizing gas through said formation when the temperature within said formation traversed by the oxidizing gas passed from said last-mentioned input well begins to approach the ignition temperature of said hydrocarbon material, and

thereafter passing an inert driving fluid through said formation from an input well to an output well to drive heated fluid hydrocarbons within said formation to said latter output well.

3. The procedure of claim 2 wherein at least one of said steps of passing oxidizing gas through said formation is repeated at least once.

4. The procedure of claim 2 wherein both of said steps of passing oxidizing gas through said formation is repeated at least once.

5. A procedure for recovering hydrocarbons from a subterranean formation containing hydrocarbon material comprising:

passing an oxidizing gas through said formation from an input well to an output well,

maintaining said passage of said oxidizing gas through said formation to effect auto-oxidation of said hydrocarbon material in said formation traversed by the oxidizing gas passed from said input well and thereby heat said hydrocarbon material until the carbon dioxide content of the effluent gas from said formation to said output well exceeds about 3 percent by volume,

thereafter passing oxidizing gas through said formation traversed in said first passage of oxidizing gas from an input well to an output well in a direction through said formation substantially opposite to the direction of said oxidizing gas in said first passage of said oxidizing gas through said formation,

maintaining said passage of said oxidizing gas through said formation to effect auto-oxidation of said hydrocarbon material in said formation traversed by the oxidizing gas passed from said last-mentioned input well and thereby heat said hydrocarbon material until the carbon dioxide content of the effluent gas from said formation to said output well exceeds about 3 percent by volume, and

passing an inert driving fluid through said formation from an input well to an output well to drive heated fluid hydrocarbons within said formation to said latter output well.

6. A procedure for recovering hydrocarbons from a subterranean formation containing hydrocarbon material comprising:

as one step passing an oxidizing gas through said formation from a first well to a second well to effect auto-oxidation of said hydrocarbon material and thereby heat said hydrocarbon material,

discontinuing passage of said oxidizing gas through said formation from said first well to said second well when the carbon dioxide content of the effluent gas from said formation to said second well exceeds about 3 percent by volume,

as another step passing an oxidizing gas through said formation from said second well to said first well to effect auto-oxidation of said hydrocarbon material and thereby heat said hydrocarbon material,

discontinuing passage of said oxidizing gas through said formation when the carbon dioxide content of the effluent gas from said formation to said first well exceeds about 3 percent by volume, and

thereafter passing an inert driving fluid through said formation between said wells to drive heated fluid hydrocarbons within said formation to one of said wells.

7. The procedure of claim 6 wherein said oxidizing gas is passed into said formation from said first well to said second well and from said second well to said first well at a pressure of at least 8 atmospheres.

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8. The procedure of claim 6 wherein said oxidizing gas is air.

9. The procedure of claim 6 wherein said inert driving fluid is water.

10. The procedure of claim 6 wherein at least one of said steps of passing oxidizing gas through said formation is repeated at least once.

11. The procedure of claim 6 wherein both of said steps of passing oxidizing gas through said formation is repeated at least once.

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