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C. S. KUHN, JR.
PROCEDURE OF IN-SITU COMBUSTION FOR RECOVERY
OF HYDROCARBON MATERIAL
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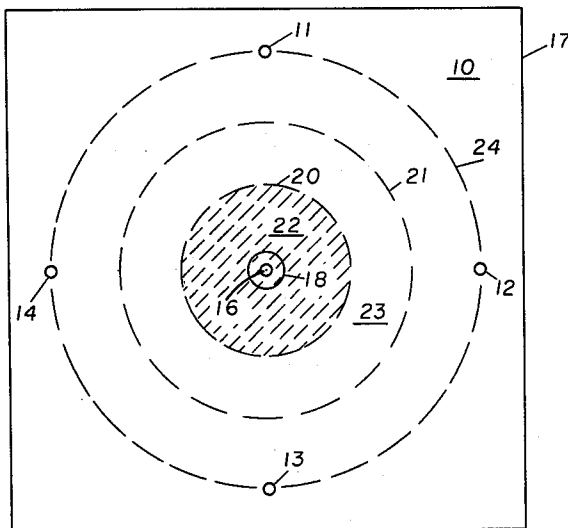


FIG. 1.

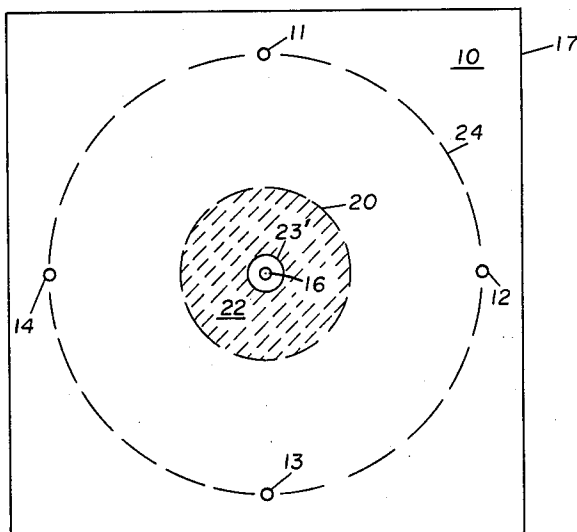


FIG. 2.

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PROCEDURE OF IN-SITU COMBUSTION FOR RECOVERY OF HYDROCARBON MATERIAL

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This invention relates to the recovery of hydrocarbon material from a subterranean formation and relates more particularly to the recovery of such material by procedures involving in-situ combustion within the subterranean formation.

Procedures for the recovery of hydrocarbon material from a subterranean formation involving combustion of a portion of the hydrocarbon material within the formation are being used to a progressively greater extent in the petroleum industry. In these operations, which are ordinarily termed "in-situ" combustion operations, an oxidizing fluid such as air is injected into the formation through an input well or wells. The formation is provided with one or more outlet, or production wells, and the oxidizing fluid flows through the formation in the direction of the outlet well or wells. Combustion of hydrocarbon material within the formation is initiated and with continued flow of oxidizing fluid through the formation a combustion front migrates through the formation. As the combustion front migrates through the formation, it displaces hydrocarbon material from within the formation and permits the hydrocarbon material to be recovered from the outlet well or wells.

In one manner of carrying out in-situ combustion operations, known as direct drive, combustion is initiated within the formation adjacent to an input well and oxidizing fluid is passed through the formation from the input well. The combustion front with continued flow of oxidizing fluid between the input well and an output well, migrates through the formation from the input well in the general direction of flow of the oxidizing fluid toward the output well. The oxidizing fluid passes through the combustion front and the hot, spent oxidizing fluid displaces hydrocarbon material from the formation leaving behind a carbonaceous deposit. The displaced hydrocarbon material flows through the formation along with the spent oxidizing fluid to the output well and the carbonaceous deposit provides the fuel for the migrating combustion front. Displacement of the hydrocarbon material is effected by a combination of factors related to the heating effect such as reduction in viscosity including vaporization, visbreaking, and incomplete oxidation. The formation in advance of the migrating combustion front is progressively cooler with distance from the combustion front. As the hydrocarbon materials displaced from the formation migrate from the combustion front, they become cooled upon passing through the cooler portions of the formation. Thus, these materials condense, or, where originally in the liquid phase, increase in viscosity. Accordingly, they become more resistant to flow through the formation and provide a block to the passage of fluid through the formation. As a result, the pressure necessary to maintain flow of the oxidizing fluid through the formation increases and this condition can result in blockage of the formation to the extent that the flow of oxidizing fluid becomes insufficient to maintain combustion. The situation becomes particularly aggravated where the hydrocarbon material in the formation is highly viscous such as is the case with tar in tar sands.

To avoid the blocking effect of the displaced fluids encountered in direct drive, it has been proposed to carry out in-situ combustion employing a reverse drive. In this manner of operation, combustion is initiated within the formation adjacent to a well and the oxidizing fluid

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for maintenance of the combustion is supplied from another well which is operated as an input well. The oxidizing fluid passes through the formation from the input well in the general direction of the well adjacent to which combustion was initiated and this well is thereafter operated as an output well. The combustion front migrates through the formation from the output well toward the input well and thus the direction of migration of the combustion front is opposite to, or countercurrent to, the direction of flow of the oxidizing fluid. The hydrocarbon material displaced by the migrating combustion front flows to an output well along with the spent oxidizing fluid. However, since the formation rearwardly of the combustion front is at a high temperature as a result of passage therethrough of the combustion front, condensation or increase in viscosity of fluids does not occur as in direct drive operations. Accordingly, problems of fluid blockage with consequent increase in pressure of the oxidizing fluid injected through the input well to maintain a desired rate of flow of oxidizing fluid do not arise. On the other hand, the displaced hydrocarbon materials all pass through the combustion front with the result that they become highly heated and cracked. Thus, the products obtained by reverse combustion are cracked products. Further, because of the reverse flow of oxidizing fluid, the combustion front does not migrate through the formation which has been stripped of hydrocarbon materials by heated fluids preceding the combustion front. As a result, the fuel consumed is hydrocarbon material and the portion of the formation through which the combustion front has migrated becomes filled with carbonaceous deposit. Thus, to the extent that hydrocarbon material is consumed as fuel by the migrating combustion front, the reverse drive results in recovery of less hydrocarbon material than the direct drive. Additionally, for reverse drive, the rate of flow of oxidizing fluid required for successful operation is greater than that required for direct drive.

It is an object of this invention to provide a method for the recovery of hydrocarbon materials from a subterranean formation by in-situ combustion. It is another object of this invention to recover hydrocarbon materials from a subterranean formation containing viscous hydrocarbon materials. It is another object of this invention to avoid the occurrence of a block to the passage of fluid through the formation in a direct drive in-situ combustion operation. It is another object of this invention to increase the extent of recovery of viscous hydrocarbon materials from a subterranean formation by in-situ combustion. These and further objects of the invention will become apparent from the following detailed description.

In accordance with the invention, combustion is initiated within a subterranean formation containing a hydrocarbon material, a reverse drive combustion operation is carried out to effect migration of a combustion front through a portion only of the formation, and thereafter a direct drive combustion operation is carried out to effect migration of a combustion front in the same direction through the formation as the combustion front in the reverse drive.

My invention is based upon the observation that passage of an oxidizing fluid through a subterranean formation, without more, results in oxidation of the hydrocarbon material within the formation. This oxidation occurs at a low rate and the exothermic heat of reaction consequently is released slowly. The oxidation reaction is a low temperature reaction and under ordinary circumstances the temperature of the formation in which the hydrocarbon material is undergoing this oxidation rises to only an insignificant degree.

My invention is also based upon the further observa-

tion that the rate of oxidation of the hydrocarbon material within a subterranean formation by passage therethrough of an oxidizing fluid is extremely sensitive to the temperature within the formation. At temperatures ordinarily prevailing within a subterranean formation, the rate of oxidation is sufficiently low that the temperature of the formation increases to only a slight extent. However, with increase in temperature within the formation, the rate of oxidation increases rapidly. Ordinarily, the time required for a rise in temperature sufficient to decrease the viscosity of the hydrocarbon material within a formation to a practical degree, from the standpoint of ease of moving the hydrocarbon material through the formation for recovery, can be a matter of years. However, with an increase in the temperature within the formation of only a few degrees, the rate of oxidation is increased such that the rise in temperature effected by the oxidation is sufficient to decrease the viscosity of the hydrocarbon material to a practically significant degree. Further, the effect of temperature rise upon the rate of oxidation, and thus the temperature achieved by the oxidation, is cumulative, i.e., with rise in temperature the rate of reaction is increased with consequent further rise in the temperature and increase in the rate of reaction.

In the following table, there is illustrated the effect of temperature upon the rate of oxidation of a hydrocarbon material. The hydrocarbon material was Athabaska tar sand containing 13.5 percent by weight of tar and the oxidizing fluid was oxygen. In each run, the tar sand was placed in a reactor maintained throughout the run at the temperature indicated, the reactor was evacuated, and the reactor was then charged to 80 pounds per square inch with oxygen. Oxidation of the tar sand was exhibited by a decrease in the pressure of the oxygen. The pressure decrease was measured and a pressure-time record was made to obtain reaction rate data. Initial rates of oxidation in standard cubic feet of oxygen per cubic foot of tar sand were measured from the pressure-time data.

Run Number	Temperature, °F.	Initial Rate of Oxygen Uptake, s.c.f.d./ft. ³ tar sand
1	121	0.05
2	146	0.57
3	180	1.30
4	225	5.22
5	242	6.28

By the procedure of the invention, in the first stage thereof, a reverse drive combustion operation is carried out. In the reverse drive combustion operation, the oxidizing fluid is passed through an input well to the formation and through the formation to an output well. The combustion front migrates from the output well through the formation in the direction of the input well. While the combustion front is migrating from the output well, the oxidizing fluid passing through the portion of the formation between the input well and the combustion front effects low temperature oxidation of the hydrocarbon material in that portion of the formation. At the input well, the temperature of the formation will be at a minimum. Thus, initially, at this portion of the formation, the rate of oxidation will be at a minimum. On the other hand, at the combustion front, the temperature of the formation will be at a maximum. The formation is thermally conductive and heat will migrate through the formation from the combustion front. Part of this heat will migrate through the formation in the direction of the input well and, accordingly, there exists in the formation a heated zone preceding the combustion zone in the direction of the input well. The oxidizing fluid passing through this heated zone effects oxidation therein and, since the zone

is at a progressively higher temperature from its leading edge to its trailing edge adjacent to the combustion zone, this oxidation is at a comparatively rapid rate and the temperature of the heated zone accordingly is appreciably increased. With increase in temperature of the heated zone, heat is conducted through the formation from the heated zone in the direction of the input well. The area of the heated zone is thus increased. The oxidizing fluid passing through the portions of the formation included within the increased area of the heated zone effects oxidation therein at an accelerated rate and the temperature rises with further increase in the area of the heated zone. There is thus created in the formation, as a result of oxidation of the hydrocarbon material by the oxidizing fluid and the initiating, or triggering, action of the combustion front, a continually expanding heated zone between the input well and the combustion front. The rate of expansion of the heated zone is in excess of the rate of migration of the combustion zone. Eventually, the heated zone expands as far as the input well.

The hydrocarbon material within the heated zone will, as a result of increase of temperature, be reduced in viscosity. As a result of reduction in viscosity, the hydrocarbon material will be enabled to flow more easily through the formation. The portion of the formation between the output well and the combustion front, i.e., that portion of the formation through which the combustion front has passed, will have been depleted of hydrocarbon material and will contain carbonaceous residue.

The reverse drive combustion operation is continued at least until the leading edge of the heated zone has arrived at the input well. The reverse drive combustion operation can be continued after the leading edge of the heated zone has arrived at the input well. This can be the case particularly where a plurality of input wells are employed and the leading edge of the heated zone has arrived at one or more of the input wells before it has arrived at the remainder of the input wells. However, it is preferred that the reverse drive combustion operation be discontinued as soon as possible following arrival of the leading edge of the heated zone at the input well. With arrival of the leading edge of the heated zone at the input well and continuation of the reverse drive combustion operation, the temperature of the formation in the vicinity of the input well will progressively increase and the viscosity of the hydrocarbon material within the portion of the formation in the vicinity of the input well will progressively decrease. The longer the reverse drive combustion operation is continued the lower will be the viscosity of the hydrocarbon material at the input well and the greater the ease of flow through the formation. On the other hand, the longer the reverse drive combustion operation is continued the greater will be the amount of hydrocarbon material converted to carbonaceous residue. Thus, with continuation of the reverse drive combustion operation, there is a resulting decrease in the total potential recovery of hydrocarbon material from the formation. Accordingly, the reverse drive combustion operation should be discontinued when the viscosity of the hydrocarbon material within the formation in the vicinity of the input well becomes sufficiently low that it may be produced from the well without blockage by displaced fluids during the subsequent direct drive combustion operation. The reverse drive combustion operation can be discontinued when the hydrocarbon material in the vicinity of the input well has attained a viscosity not greater than about 100 centipoises.

Following the reverse drive combustion operation, a direct drive combustion operation is carried out. In this direct drive combustion operation, the direction of migration of the combustion front through the formation is the same as the direction of migration of the combustion

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front in the reverse drive combustion operation. This can be conveniently accomplished by converting the well operated as the output well during the reverse drive to an input well and converting the well operated as the input well during the reverse drive to an output well. However, if desired, a different input well or wells and a different output well or wells may be employed. Combustion is initiated within the formation at the input well and oxidizing fluid is passed through the input well to the formation and through the formation to the output well. The combustion front migrates from the input well through the formation in the direction of the output well.

During the initial stages of the direct drive combustion operation, the fuel consumed by the migrating combustion front is the carbonaceous deposit produced by the migrating combustion front during the reverse drive combustion operation. The heated products of combustion from the combustion front pass through the formation in the direction of the output well. As these heated products of combustion pass through the portion of the formation into which the reverse drive combustion front did not enter, they displace the hydrocarbon materials contained within that portion of the formation. However, these displaced hydrocarbon materials do not now enter a cold portion of the formation where they condense and increase in viscosity to form a liquid block to the flow of fluid through the formation. Rather, they enter a portion of the formation which has been heated by the expanding heated zone produced during the reverse drive combustion operation. Thus, they do not condense or otherwise increase in viscosity but flow readily through the formation in the direction of the output well along with the spent oxidizing fluid.

With continuation of the direct drive operation, the portion of the formation into which the combustion front did not enter during the reverse drive operation will be entered by the combustion front. The heated hydrocarbon materials, plus the heated spent oxidizing fluid, displace hydrocarbon materials from the formation leaving behind carbonaceous deposit. The fuel consumed thereafter will be the carbonaceous deposit formed during the direct drive operation. Thus, in the direct drive operation, appreciable amounts of hydrocarbon material *per se* are not consumed as fuel. To the extent that hydrocarbon material is not consumed as fuel in the direct drive combustion operation, the extent of recovery of hydrocarbon material from the formation, over that which would be attained by a reverse drive combustion operation, is increased.

FIGURE 1 is a schematic diagram illustrating the reverse drive combustion operation of the invention.

FIGURE 2 is a schematic diagram illustrating the direct drive combustion operation of the invention.

Referring now to FIGURE 1, formation 10 is penetrated by wells 11, 12, 13, 14, and 16. These five wells are arranged within the area 17, as shown, with well 16 centrally located with respect to wells 11, 12, 13, and 14. This arrangement of the wells is known customarily as a five-spot well pattern. The area 17 may be the only portion of the formation provided with wells. In such case, the five wells will be the only wells penetrating the formation and the five wells will constitute an isolated pattern. On the other hand, other areas of the formation may be provided by wells in which case the five wells will constitute part of a developed pattern.

In the reverse drive combustion operation, wells 11, 12, 13, and 14 are operated as input wells. Well 16 is operated as an output, or production, well. Combustion is initiated within the formation 10 adjacent to well 16. For initiating combustion, any conventional method may be employed. Further, in the initiation of combustion, oxidizing fluid for the combustion may be provided by injecting the fluid into the formation through well 16. Alternatively, the oxidizing fluid may be provided by injecting the fluid into the formation through one or more

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of the input wells 11, 12, 13, or 14. Upon initiation of combustion, oxidizing fluid for migration of the combustion front through the formation is provided by injection into each of the input wells 11, 12, 13, and 14.

The oxidizing fluid flows through the formation 10 from each of the input wells to the output well 16. The combustion front, indicated in its initial stage by the circle 18, advances radially through the formation toward the input wells. With injection of oxidizing fluid and passage through the formation, oxidation of the hydrocarbon material within the formation between the input wells 11, 12, 13, and 14 and the advancing combustion front 18 occurs with increase in temperature. Heat flows through the formation from the combustion front 18 by conduction in the direction of the input wells countercurrently to the flow of the oxidizing fluid. In the portion of the formation, in the direction of the input wells affected by the heat conducted from the combustion front, oxidation occurs at an accelerated rate and the temperature of this portion of the formation rises at an accelerated rate. The accelerated rate of oxidation produces a heat front which extends outwardly from the combustion front in the direction of the input wells. With the combustion front in the position indicated by the circle 20, the heat front will be in the position indicated by the circle 21. In the area 22, between the output well 16 and the combustion front 20, the formation will contain carbonaceous residue. In the area 23, between the combustion front 20 and the heat front 21, the formation will have been depleted of lighter hydrocarbon material. The remainder of the hydrocarbon material, also as a result of the heating, will have been decreased in viscosity making its flow through the formation, under the conditions of drive of the oxidizing fluid, easier.

During the reverse drive combustion operation, hydrocarbon products, and products of combustion, flow through the formation in the direction of the flow of oxidizing fluid to the output well from which they are recovered. Eventually, with continuation of the reverse drive combustion operation, the heat front can arrive at each of the input wells. In this situation, the heat front will be in the position indicated by the circle 24.

Following the reverse drive combustion operation, the direct drive combustion operation is initiated. It is preferred, following the reverse drive combustion operation, to permit a waiting period to elapse before initiating the direct drive combustion operation. This waiting period permits heated hydrocarbon material within the formation to migrate to zones within the formation of higher permeability. As a result of this migration, ease of recovery of hydrocarbon materials during the subsequent operations is improved. The waiting period may be, for example, between four and six weeks. However, the waiting period should not be so long that cooling, with increase in the viscosity of the hydrocarbon material within the formation to the point where recovery during the direct drive combustion operation is hindered, occurs.

Referring to FIGURE 2, during the direct drive combustion operation, well 16 is operated as an input well and wells 11, 12, 13 and 14 are operated as output wells. Oxidizing fluid is injected into well 16 and flows through the formation 10 into the direction of the output wells 11, 12, 13, and 14. Combustion is initiated within the formation at the input well 16 and a combustion front, indicated in its early stages by the circle 23', migrates radially through the formation from the well 16 to the wells 11, 12, 13, and 14. The fuel for the combustion at this stage is the carbonaceous residue deposited in the area 22 between the well 16 and the circle 20, the termination position of the previous combustion front, during the reverse drive combustion operation. Behind the combustion front, the formation will have been burned clean of carbonaceous residue. With migration of the combustion front through the formation in the direction of the output wells 11, 12, 13, and 14, the hydrocarbon ma-

terial remaining within the area 22 from the reverse drive combustion operation will be moved through the formation in the direction of flow of the oxidizing fluid.

Upon continued injection of oxidizing fluid into well 16, the combustion front advances further through the formation. Eventually, the combustion front will arrive at the circle 20, the position occupied by the combustion front at the termination of the reverse drive combustion operation. The carbonaceous residue previously deposited within the area 22 during the reverse drive combustion operation will have been consumed. Fuel for further migration of the combustion front will be carbonaceous residue formed within the portion of the formation between the circle 20 and the output wells by thermal cracking just ahead of the combustion zone.

The spent oxidizing fluid passing through the formation in advance of the combustion front strips hydrocarbon material from the formation and moves it through the formation into the direction of the output wells. The entire portion of the formation between the input well 16 and the position attained by the heat front during the reverse drive combustion operation, in this case the circle 24, will have been heated during the reverse drive combustion operation. The hydrocarbon material stripped from the formation by the advancing combustion front in the direct combustion operation and advancing to the output wells passes through the formation which is at an elevated temperature. Thus, the hydrocarbon material remains at an elevated temperature in its passage through the formation to the output wells. Condensation, if any, of vaporized hydrocarbon material and increase in viscosity of liquid hydrocarbon material is at a minimum. Accordingly, blockage to the flow of oxidizing fluid through the formation as a result of condensation of vaporized hydrocarbons and increase in the viscosity of liquid hydrocarbons does not occur. The hydrocarbon material readily flows through the formation to the output wells from which it is recovered.

The direct drive combustion operation may be continued to the extent desired. The extent to which this operation is continued can be in accordance with standard practice in connection with direct drive combustion operations. For example, the direct drive combustion operation may be continued until breakthrough of the combustion front at one or more of the output wells. On the other hand, the direct drive combustion operation may be discontinued prior to arrival of the combustion front at any of the output wells or may be discontinued until breakthrough has occurred at each of the output wells. If desired, the direct drive combustion operation may be repeated at least once.

The procedure of the invention may be employed in connection with any pattern of input well or wells and output well or wells. The pattern may be an isolated pattern or a developed pattern. The pattern may be a five-spot pattern or a seven-spot pattern. If desired, the wells may be in parallel lines with alternate wells in a given line operated as input wells and output wells, respectively, and either simultaneously or subsequently the alternate wells in another line parallel thereto operated as input wells and output wells, respectively.

The procedure of the invention may be also carried out in any type of subterranean formation containing hydrocarbon material or a material providing a source of hydrocarbon material. 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. The formation may be a formation containing petroleum oil or may be a tar sand or may be an oil shale formation. Further, the formation may have been partially depleted. The procedure of the invention is preferably employed for the treatment of a formation wherein the produced hydrocarbon material is highly viscous.

The procedures described are susceptible to various modifications. For example, during initiation of combustion, for the reverse drive combustion and the direct drive combustion operations, a combustible material, such as natural gas, may be employed to assist in initiation of combustion. Additionally, where the formation is relatively thick, the levels at which the combustion operations are carried out may be selected in order to obtain optimum migration of the hydrocarbon materials to the zones of relatively high permeability. Thus, the reverse drive combustion operation may be initiated near the top of the formation and the direct drive combustion operation may be initiated near the bottom of the formation. On the other hand, the reverse drive combustion operation may be established near the bottom of the formation or at a level intermediate to the top and bottom of the formation and the direct drive combustion operation initiated either above, below, or at substantially the same level as the reverse drive combustion operation. Successive reverse drive and successive direct drive combustion operations may be carried out at different levels to insure a maximum recovery of hydrocarbon material from the formation. These and other modifications of the invention will suggest themselves to those skilled in the art.

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 process for the recovery of hydrocarbon material from a subterranean formation containing a source material thereof comprising:

passing a first combustion front by reverse combustion through at least a portion of said formation between an output well and an input well by igniting said source material at said output well and passing oxidizing fluid through said formation to said output well from said input well whereby said combustion front migrates through said formation in a direction from said output well to said input well and forms a carbonaceous residue within said formation over the portion thereof through which said combustion front migrates and a heat front precedes said combustion front in the direction of said input well and permits low temperature oxidation of said source material to occur within the portion of said formation between said combustion front and said input well;

producing hydrocarbon material from said output well; discontinuing passage of said oxidizing fluid through said formation when said combustion front has migrated a portion only of the distance between said output well and said input well and the leading edge of said heat front reaches said input well so that said formation between said output well and said input well will consist of a portion over which said combustion front has migrated containing carbonaceous residue and a portion over which low temperature oxidation of said source material has occurred;

thereafter passing a second combustion front by direct combustion through said formation between an input well leading to said formation at a point in contact with said carbonaceous residue and an output well located within said portion of said formation over which low temperature oxidation of said source material only has occurred by igniting said carbonaceous residue at said input well and passing oxidizing fluid through said formation to said output well from said input well whereby said combustion front migrates through said formation in a direction from said input well to said output well;

continuing passage of said oxidizing fluid through said formation until said combustion front has passed first through at least a portion of said formation over which said first combustion front has migrated and thereafter through at least a portion of said formation over which low temperature oxidation of said source material has occurred; and

producing hydrocarbon material from said output well.

2. A process for the recovery of hydrocarbon material from a subterranean formation containing a source material thereof comprising:

passing a first combustion front by reverse combustion through at least a portion of said formation between an output well and an input well by igniting said source material at said output well and passing oxidizing fluid through said formation to said output well from said input well whereby said combustion front migrates through said formation in a direction from said output well to said input well and forms a carbonaceous residue within said formation over the portion thereof through which said combustion front migrates and a heat front precedes said combustion front in the direction of said input well and permits low temperature oxidation of said source material to occur within the portion of said formation between said combustion front and said input well;

producing hydrocarbon material from said output well; discontinuing passage of said oxidizing fluid through said formation when said combustion front has migrated a portion only of the distance between said output well and said input well and the leading edge of said heat front reaches said input well so that said formation between said output well and said input well will consist of a portion over which said combustion front has migrated containing carbonaceous residue and a portion over which low temperature oxidation of said source material has occurred;

thereafter passing a second combustion front by direct combustion through said formation between an input well located within said portion of said formation through which said first combustion front has migrated and an output well located within said portion of said formation over which low temperature oxidation of said source material only has occurred by igniting said carbonaceous residue at said input well and passing oxidizing fluid through said formation to said output well from said input well whereby said combustion front migrates through said formation in a direction from said input well to said output well;

continuing passage of said oxidizing fluid through said formation until said combustion front has passed first through at least a portion of said formation over which said first combustion front has migrated and thereafter through at least a portion of said formation over which low temperature oxidation of said source material has occurred; and

producing hydrocarbon material from said output well.

3. A process in accordance with claim 2 wherein passage of oxidizing fluid through the formation is discontinued when, in addition to migration of the first combustion front for only a portion of the distance between the output well and the input well and arrival of the leading edge of the heat front at the input well, the viscosity of the source material at the input well is, as a result of heating by low temperature oxidation, not greater than about 100 centipoises.

4. A process for the recovery of hydrocarbon material from a subterranean formation containing a source material thereof comprising:

passing a first combustion front by reverse combustion through at least a port of said formation between a first well and a second well by igniting said source material at said first well and passing oxidizing fluid through said formation to said first well from said second well whereby said combustion front migrates through said formation in a direction from said first well to said second well and forms a carbonaceous residue within said formation over the portion thereof through which said combustion front migrates and a heat front precedes said combustion front in the direction of said second well and permits low temperature oxidation of said source material to occur within the portion of said formation between said combustion front and said second well;

producing hydrocarbon material from said first well; discontinuing passage of said oxidizing fluid through said formation when said combustion front has migrated a portion only of the distance between said first well and said second well and the leading edge of said heat front reaches said second well so that said formation between said first well and said second well consists of a portion over which said combustion front has migrated containing carbonaceous residue and a portion over which low temperature oxidation of said source material has occurred;

thereafter passing a second combustion front by direct combustion through said formation from said first well in the direction of said second well by igniting said carbonaceous residue at said first well and passing oxidizing fluid through said formation to said second well;

continuing passage of said oxidizing fluid through said formation until said combustion front has passed through at least a portion of said formation over which said first combustion front has migrated and thereafter through at least a portion of said formation over which low temperature oxidation of said source material has occurred; and

producing hydrocarbon material from said second well.

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