Aug. 25, 1959 F. E. CAMPION ET AL **2,901,043**

HEAVY OIL RECOVERY

Filed July 29, 1955 2 Sheets-Sheet 1

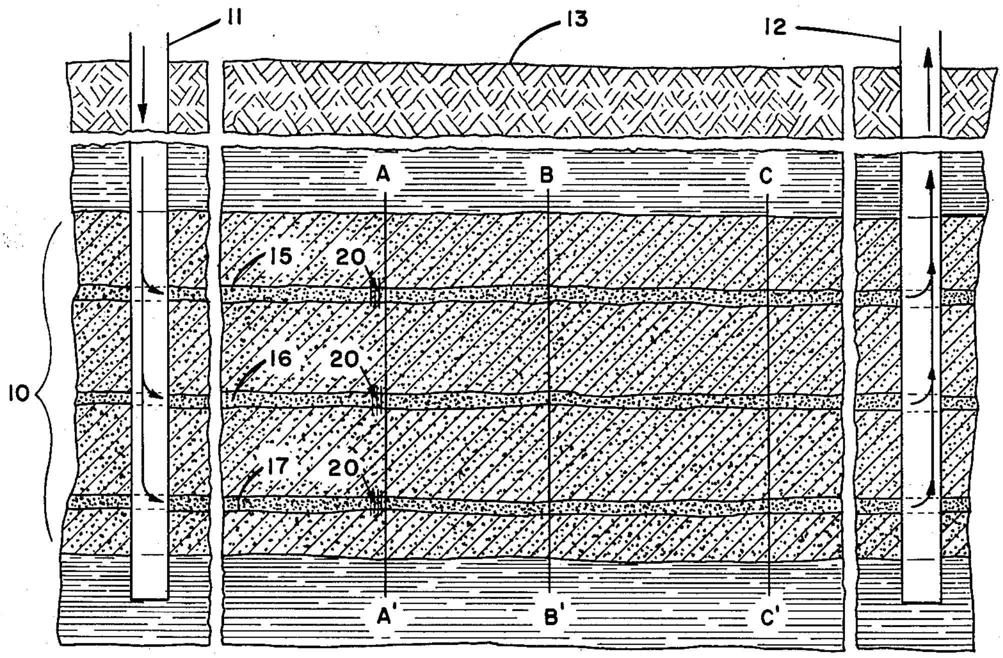

FIG. 1

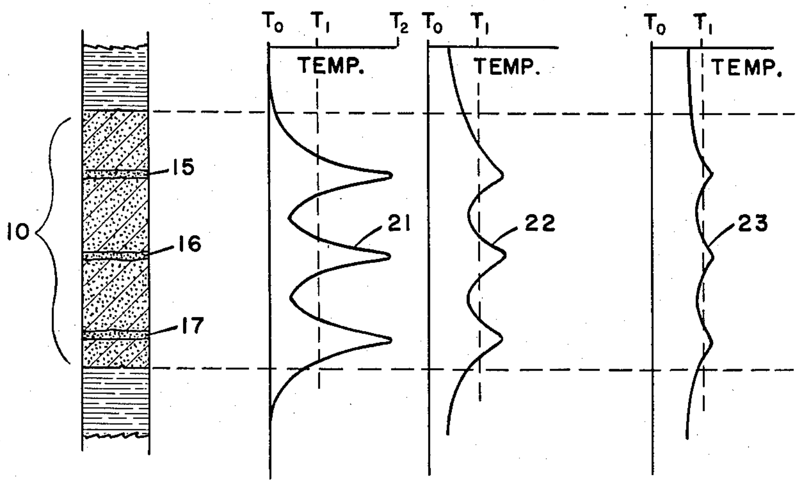

FIG. 2

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2 Sheets-Sheet 2

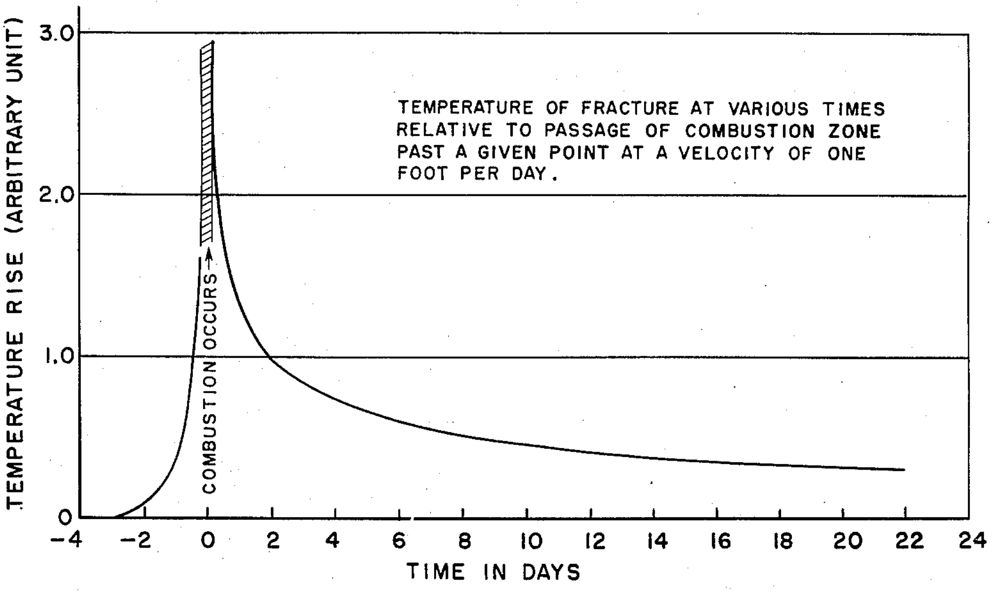

FIG. 3

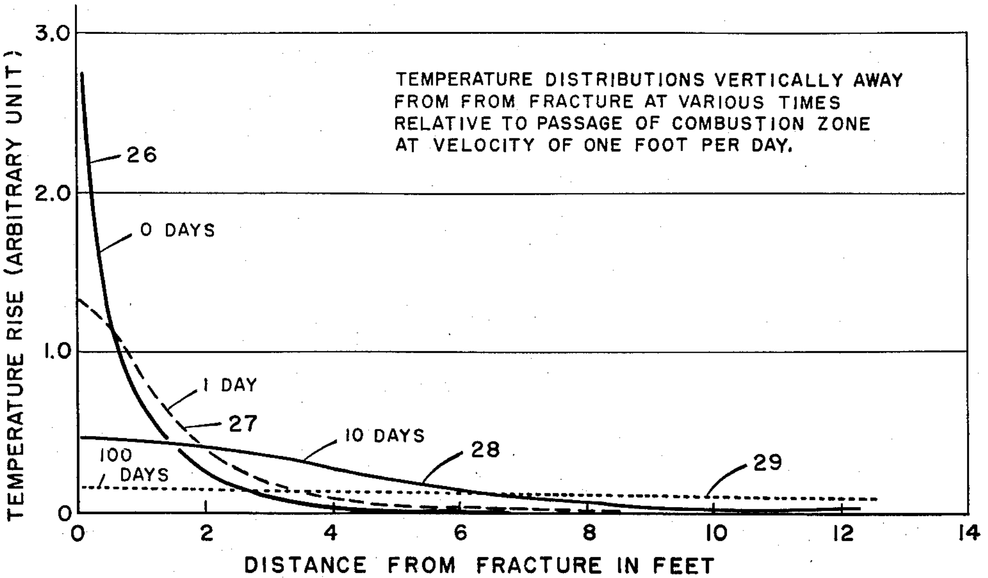

FIG. 4

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HEAVY OIL RECOVERY

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Application July 29, 1955, Serial No. 525,284

4 Claims. (Cl. 166—11)

This invention relates to the recovery of oil or hydrocarbons from the underground strata in which they occur and is directed particularly to the recovery of heavy oils and similar carbonaceous substances by applying heat to them. More specifically, the invention is directed to a process or method of heavy oil recovery by heating wherein the heat is generated by combustion or oxidation within the deposit or reservoir stratum itself.

There are many known fields where the percentage of oil recovery is quite low. This may be due to one or a combination of several causes. In some fields, the poor recovery of oil is due mostly to unfavorable conditions of porosity and/or permeability of the reservoir medium. In other fields it is known that these latter conditions are favorable, and the poor recovery of oil is due to the characteristics of the oil itself, such as high viscosity, low gas saturation, or high wax content. It is in the latter type of reservoir that our invention is most useful for improving recovery, but its utility is not necessarily limited to such fields.

Over a substantial period of years, many suggestions have been made for improving recovery by applying heat to make oil more easily recoverable in various ways, such as by increasing vapor pressure or reducing viscosity. Some of these suggestions have been tried with varying degrees of success. The usefulness of many of these methods or suggestions has been limited in a number of ways. For example, some types of recovery operations may require injection pressures that are so high as to be uneconomical; the required volumes of gas to be injected may be excessively large per barrel of liquid recovered; the minimum temperatures which can be maintained may still be higher than are desirable or necessary; more of the hydrocarbons in place may be consumed than is necessary or desirable; heat losses may be excessive; only one pass through the reservoir formation can be made, and if this is unsuccessful, it cannot be repeated; the progress of the heat-generating combustion front or wave may be difficult to vary or control; the area of operation of the recovery process may be a constantly expanding one, ultimately requiring very large capacities of energy input; and oxygen enrichment may be required at additional expense.

The primary object of our invention accordingly is to provide, for the recovery of heavy oils, tar, and like carbonaceous substances, a process or method which utilizes heat generated by combustion within the producing formation in a way or manner which avoids or overcomes most of the foregoing mentioned difficulties or disadvantages. More specific objects of our invention are to provide an underground combustion process by which: (1) a controllable and limited amount of heat is generated within the formations, so as to obtain any desired degree of viscosity reduction and other accompanying effects, without simultaneously causing overheating of the formation in places or overheating and cracking of the bulk of the in-place hydrocarbons; (2) extraneous fuel may be utilized to any desired extent

to conserve the hydrocarbons it is desired to recover; (3) more than one pass through a given formation can be made whenever desired; (4) the generation of heat acts as an aid to more conventional methods of recovery; (5) a fractional recovery can be effected to recover only the most volatile, and often the most valuable, fractions of the oil in place, leaving behind only the least desirable heavy constituents; (6) if necessary or desirable, the generation of heat by combustion can be discontinued at any time and restarted or repeated as desired at some later time; (7) recovery can be carried out completely in any small portion of a large field without affecting the remainder of the field and without need for a large plant investment to supply an ever-increasing amount of input energy. Other and further objects, uses, and advantages of the invention will become apparent as the description proceeds.

Stated in a most brief fashion, the foregoing and other objects are accomplished by our invention by performing what may be designated as backward or countercurrent combustion in fractures.

In conventional recovery processes, involving the injection of a drive-producing medium through a first well and recovery of the products from a second well spaced at some distance from the first, it is ordinarily considered a disadvantage to have highly permeable streaks or strata extending between the two wells. These are thought to cause channeling of the injected fluids, which results in the bypassing of portions of the oil in place. Thus, efforts are ordinarily made to equalize the formation permeability by closing off the most permeable streaks, leaving a substantially uniform but somewhat lower overall value of permeability of the formation to be subjected to the recovery process.

In our invention, on the other hand, such highly permeable horizontal streaks or channels as are normally closed off are not only necessary, but, if they are not naturally present at the appropriate places, they must be artificially created. Our invention accordingly comprises providing at least one input well and one or more output wells spaced therefrom in a producing horizon, which wells are connected by either naturally occurring or artificially induced horizontal fractures within the producing formation. Combustion is initiated at the bore of the output well in any suitable manner. This combustion is supported by supplying an oxygen-containing gas, preferably air, alone or in a combustible mixture along with a fuel gas, preferably natural gas. The oxygen-containing gas or mixture is injected through the input well and flows through the fracture or fractures to the initiated zone of combustion at the bore of the output well. This mode of oxygen supply causes the combustion zone or zones to move slowly through the fractures away from the output well bore toward the source of oxygen at the input well.

During this movement, the heat generated by combustion occurring chiefly within the fractures diffuses vertically through the reservoir stratum by conduction through the reservoir rock. The heavy oil or other carbonaceous material in the rock pore spaces has its viscosity lowered, its vapor pressure increased, and/or one or more of several additional effects may occur.

By gravity flow, the reduced viscosity oil or hydrocarbon may enter the fractures and be driven to the output well by the flow of combustion product gases through the fractures. The heat diffusing through the rock may cause evolution of gases from, or vaporization of light components of, the oil within the rock pore spaces, thereby forcing the oil out of the pore spaces and into the permeable fractures. Also, the heating may be sufficient to vaporize the connate water normally present within most formations, thus subjecting the oil and reservoir rock to a kind of steam-pressure drive and stripping action. Also, the viscosity of the oil may be lowered to the point where the pressure of gas injected within the reservoir rock itself can drive the oil to the output well. Regardless of which one or what combination of these mechanisms is brought into play, the net result of reservoir heating in the manner described, by diffusion of heat from zones of combustion within fractures, is a substantial increase in the percentage of oil recovery.

This will be better understood by reference to the accompanying drawings forming a part of this application and showing diagrammatically and graphically an embodiment of the invention and the relationships of certain variables. In these drawings,

Figure 1 is a diagrammatic cross-sectional view through a section of the earth between two wells which penetrate an oil-bearing stratum to be subjected to recovery according to the invention;

Figure 2 shows logs of varying temperature distributions through the producing and adjacent strata;

Figure 3 is a typical graph of the temperature variation with time at a point within a fracture before and after passage of a combustion zone; and

Figure 4 shows graphs of typical temperature variations as a function of distance from a fracture, at various times relative to the passage of a combustion zone through the fracture.

Referring now to these drawings in detail and particularly to Figure 1 thereof, an oil-bearing stratum **10** is shown diagrammatically in cross section as penetrated by two spaced wells **11** and **12**, which are drilled from the ground surface **13** through the stratum **10**. Extending horizontally between the wells **11** and **12** through the stratum **10** are a plurality of horizontal fractures **15**, **16**, and **17**. Besides extending between the wells **11** and **12** as shown on the drawing, it is to be understood that the fractures **15**, **16**, and **17** normally extend in all directions around the various wells penetrating stratum **10**, including other wells not shown, and in this way these fractures cover substantially the entire horizontal area of the stratum **10** from which oil is to be recovered.

By the term "fracture," as used herein, it is intended to include both natural and artificially created fractures or highly permeable streaks. Thus the fractures **15**, **16**, and **17** may be either artificially created highly permeable streaks or channels created by hydraulic pressure and propped open by solid particles such as sand, by processes of hydraulic fracturing well known in the art, or they may be naturally occurring streaks of high permeability.

The vertical spacing or depth interval of the fractures within the stratum **10** is a matter of some importance. Preferably the fractures are spaced approximately uniformly apart in depth. As in a majority of cases naturally occurring fractures or permeable streaks will not be present at the desired levels within the stratum **10**, a usual preliminary step in recovering oil by our process comprises artificially creating fractures at the desired depths between and around the wells **11** and **12**. For example, by hydraulic fracturing, horizontal channels are created around the well **11** extending to distances at least as great as the bore of well **12**. These same fractures can then be enlarged and extended further around well **12** by injecting fracturing media into it. In a similar way, other wells not shown can be connected into the original set of fractures created between the two illustrated wells **11** and **12**. Also, if desired, the capacity of natural fractures may be enlarged by causing one or more of the artificial fractures to pass along them.

The vertical positions of the fractures **15**, **16**, and **17** with respect to the boundaries of the stratum **10** are also of importance. From the viewpoint of maximum utilization of heat, a single fracture passing horizontally through the center of the stratum would be the most efficient, but this would serve as a gravity drainage flow channel for only the upper half of the formation **10**. For most efficient recovery by gravity drainage, a single channel at the lower formation boundary would be best, but this would involve a loss of about half of the generated heat to the underlying strata. In practice, these two conflicting requirements are compromised by using two or more fractures simultaneously, one of which is preferably near the bottom of the stratum, such as is exemplified by the fracture **17**, while the other or others are spaced approximately uniformly throughout the rest of the producing stratum **10** thereabove.

With the fractures **15**, **16**, and **17** avaliable, the recovery of oil by the process of our invention is begun by initiating combustion at the bore of the output well **12**. This may be done in any of several ways. For example, the face of the formation **10** exposed in the bore of well **12** is heated to above the ignition temperature of the combustible gas-air mixture to be burned by means of a well-bore heater. This may be either electrical or one fired by a combustible mixture of gases injected down tubes inserted into well **12**. During and/or immediately after the initial heating of the well bore **12**, combustion-supporting, oxygen-containing gas is injected down input well **11**, whence it flows through the fractures **15**, **16**, and **17** to the bore of well **12** where combustion within the fractures then begins. This combustion continues as long as oxygen-containing gas is supplied, while the location of the zones of combustion slowly moves away from well **12** through the fractures toward well **11**.

The mechanism by which this countercurrent combustion zone propagation takes place is qualitatively simple, though somewhat difficult to describe quantitatively. Consider a first point within a fracture where combustion is occurring. The heat released at this point flows by conduction through the rock in any direction where the temperature is lower. Thus, the heat travels not only vertically away from the point of combustion, but also horizontally along the fracture in the countercurrent direction. As a result, a second point in the rock at the boundary of the fracture in the upstream direction subsequently becomes heated to a temperature high enough to ignite the combustible gas mixture arriving there, combustion and heat release then occur at the second point, some heat travels to a third point still further upstream, and so on. In reality of course, all these phenomena occur smoothly and in a continuous manner, rather than in the point-to-point fashion assumed for explanation.

As combustion-supporting gases continue to be injected into well **11** and through the fractures to the combustion zones therein, increasingly greater amounts of heat are released within the fractures at the locations of the combustion zones. By conduction this heat diffuses through the reservoir medium to the portions of stratum **10** lying between and above or below the fractures. As the temperature of the oil in stratum **10** near well **12** rises due to this heat transfer, the oil flows to the well bore **12** by any of several paths. By the formation of gas bubbles within the reservoir rock medium, the oil may be forced out of the pore spaces and directly into well **12**. By heating, the oil viscosity may be reduced to the point where it flows readily by gravity to one of the fractures **15**, **16**, or **17**, where the rapidly flowing combustion product gases sweep it along the fracture into well **12**. Removal of oil from the interior of the stratum **10** may also be assisted by the vaporization of such connate water as occurs within the rock pore spaces along with the oil, provided the temperature reaches a sufficient level for vaporization of the water at the reservoir pressure existing.

Not all of the injected oxygen or oxygen-containing gaseous mixture may flow through the fractures, but a minor proportion of the injected gases may flow also through the interior of the stratum **10**. Upon reaching a point in the rock space between the fractures where the temperature is high enough for ignition to occur, oxidation utilizing this oxygen occurs to augment the heat cartied by diffusion through the rock from the fracture combustion zones. The main bulk of generation of heat, however, takes place within the fractures, just as the primary flow of gases is through these fractures, with only a minor proportion of the gas flow taking place through the reservoir medium. Generally speaking, the relative amounts of heat generated within the fractures and within the formation are in about the same ratio as is the flow of gas in the fractures compared to that through the formations.

The composition of the input gases to well 11 may be varied widely. As compared with concurrent combustion processes, wherein the combustion zone movement and the fluid flow through the formation are in the same direction, a particular advantage of the present invention is that as much gaseous fuel as desired may be incorporated in the input gas stream. The combustion zone nevertheless continues to propagate in the desired countercurrent direction. Thus, it is entirely possible to supply enough natural gas, for example, as fuel in the input stream to consume all of the oxygen, thereby furnishing all of the heat needed for oil recovery without requiring combustion of any substantial portion of the oil in place. In fact, if desired for any reason, natural gas could constitute a substantially larger proportion of the input gas stream than the amount required to form a stoichiometric mixture with the oxygen. Alternatively, any part of the oxygen may be consumed by the fuel gas injected along with it, and the remainder of the fuel necessary to utilize the remaining oxygen can be supplied by the oil and gas in place. The ultimate that can be accomplished in this direction, of course, is to supply only oxygen in the input gas stream, relying upon the hydrocarbons in place for the entire supply of fuel.

Also, as to inert gases or fluids, the composition of the input fluid stream can be varied widely. When using air, which is to be preferred, the inerts may constitute up to about 80 percent of the input gas stream and are principally nitrogen. This proportion may, if desired, be reduced by enriching the oxygen content of the air by any desired amount up to the use of pure oxygen, which, however, is generally not economical; or the proportion may be increased by adding inert gases such as flue gases, additional nitrogen, water vapor, and the like.

The amount of or ratio of inert gases or fluids to oxygen in the input gas stream forms an important manner of regulating the speed of propagation of the fracture combustion zone. For a given rate of oxygen supply, it is apparent that increasing the proportion of inert gases will decrease the combustion zone propagation rate, as the concurrent heat transfer by the inert gases acts in opposition to the countercurrent heat transfer by conduction through the reservoir rock. The converse of this is also true. Decreasing the proportion of inert gases or fluids in the input gas stream allows the propagation to take place more nearly at the speed of heat transfer through the rock by conduction, up to the point where a maximum propagation rate is obtained by injection of substantially pure oxygen.

A particularly efficient means for controlling, and particularly for retarding, the propagation of the combustion zones in the fractures is the judicious use of water, especially in liquid form. Water in vapor form is good as a heat-transferring inert gas, and therefore presaturating the input gas stream with water vapor is desirable when it is needed for slowing down the propagation. Water in liquid form in small amounts, either as slugs or as a continuous addition to the oxygen-containing gas mixture injected through the input well, is even more efficient at slowing down the countercurrent combustion propagation, as quite large amounts of heat can be absorbed and transferred concurrently by vaporization and condensation of the liquid water at the temperature levels existing in the combustion zone. When slugs of water are introduced and spaced by suitable intervals of time,

the temperature within the fractures may temporarily drop below ignition level. However, the intervening periods between slugs allow a reverse flow of heat from the formations, where the temperature remains high, back to the cooled fractures to occur in order to re-establish the ignition temperature within the fractures for subsequent injection of oxygen-containing gases.

Varying the oxygen rate alone is a further means of controlling the rate of combustion zone propagation. Combustion and the heat release within the fractures occur substantially in direct proportion to the rate of oxygen injection. Thus a high oxygen input rate means a rapid combustion and release of heat, a high temperature within the fracture, a high rate of diffusion of heat to the surrounding formations, and a relatively high countercurrent propagation rate of the combustion zone along the fracture. The reverse situation is also true. Low rates of oxygen injection mean low combustion and heat release rates, low rate of diffusion of heat to the surrounding reservoir, lowered peak temperatures within the fractures, and lower propagation rates of the combustion zone along the fractures.

Whether the ultimate rise in temperature that is obtained within the interior of a given formation is what is desired for the recovery of a given oil depends upon the balance established between the combustion propagation rate and the oxygen input rate. The total input of oxygen per square foot of fracture area covered by the combustion zone propagation must be such as to supply the total heat required for the recovery of oil from each square foot of the reservoir area and allow for heat losses to the adjacent strata. In determining whether the proper oxygen input and propagation rates are being obtained, heat losses to the adjacent strata can be neglected as a first approximation, because the main portion of oil recovery can be expected to occur before a large fraction of the heat generated by the combustion crosses the boundaries of the reservoir stratum and is lost to the adjacent strata.

If, in order to obtain the desired temperature rise, it is necessary to retard the propagation velocity of the combustion zone, the injection of liquid water is to be preferred as the most efficient and least expensive heat-transferring, propagation-retarding agent. Air is to be preferred as the oxygen-carrying gas because it is free. When only a small retardation of the propagation rate is desired, the nitrogen content of the air is usually sufficient to accomplish this. The presence of the nitrogen, however, does increase the compression costs of the air, but these are ordinarily less than the cost of separating the nitrogen from the input gas stream.

Referring again to the drawings, the temperature conditions within the stratum 10 after the combustion zone has propagated along the fractures 15, 16, and 17 for a period of time to the position 20, shown in Figure 1, are qualitatively shown by the graphs of Figure 2. The three graphs 21, 22, and 23 are the temperature profiles or logs as a function of depth which would be obtained along the lines A—A′, B—B′, and C—C′, respectively, shown in Figure 1. In Figure 2, the indications of these logs or profiles are correlated in position with the vertical section of the stratum 10, illustrated at the left of the figure.

Log 21, the temperature profile taken along the line A—A′, is the temperature distribution obtained just after passage of the combustion zone 20. The maximum temperature T_2 is that which is found at the locations of the fractures 15, 16, and 17 and is approximately the peak temperature which occurs within the combustion zone in the fractures. At the stratum boundaries and midway between the fractures, the temperatures shown by log 21 are only slightly above the natural temperature T_0 of the reservoir.

Log 22, corresponding to a temperature log along the line B—B′, represents the conditions existing a substantial period of time after the passage of the combustion zones 20. A substantial transfer of heat by diffusion vertically through the stratum **10** has taken place in this time interval, as is evidenced by the decrease of the peak temperatures from the value T_2 of log **21**, which is accompanied by a rise in the temperatures at the stratum boundaries and within the interior of the stratum **10** midway within the fractures.

Log **23** represents the temperature distribution across the stratum **10** and the immediately adjacent strata at the end of a still larger time interval following passage of the combustion zones **20**. This log shows how the conduction or diffusion of heat through the rock eventually brings the temperature throughout the stratum **10** close to an overall value of T_1. This is the temperature at which the desired modifications of the oil or hydrocarbon in stratum **10** are obtained to bring about its recovery.

Still further characteristics of the invention are shown by the graph of Figure 3. This is a plot of the variations of temperature with time occurring at a point within a fracture, both as the combustion zone approaches, and as it moves past and away from the point. In this case it is assumed that the combustion zone propagation rate along the fracture is one foot per day. This means, incidentally, that the abscissa scale shown as time in days is also numerically the same as the distance in feet from the point in question to the combustion zone **20**.

At this velocity in a typical medium, the temperature rise due to conduction of heat countercurrently through the rock in a horizontal direction is imperceptible about four days before the arrival of the combustion zone, or in other words about four feet in front of it. The major change in the rate of temperature rise occurs between about one and two days before the temperature zone arrives, that is, when it is still between one and two feet away. During the last day and the last one foot of travel, the temperature climbs rapidly to a value where ignition occurs and heat is released by combustion.

This combustion occurs in a relatively short time and space, and the heat so released raises the temperature of the fracture to a high value. This value is difficult to ascertain, as it depends on many factors which determine where the balance occurs between the release of the heat in the combustion and its conduction away from the fracture by the adjacent rock. Obviously, the higher the rate of heat release, as determined by the consumption of oxygen per unit time, the higher will be the temperature and the balancing rate of heat diffusion through the rock of stratum **10**.

In Figure 3, the temperature change is shown only in arbitrary units. Its absolute value depends on many variables which change it quantitatively, but not qualitatively. After the combustion zone passes the assumed observation point and has moved on, the fracture temperature decreases, at first very rapidly, and then considerably more slowly. The major drop of temperature occurs in the first two days, the decline thereafter being more and more gradual.

Still another aspect of the present invention is shown by Figure 4, which presents in greater detail than does Figure 2 the spatial temperature distribution vertically away from a given point in a fracture at several specified times relative to the time of passing of a combustion zone. The conditions for Figure 4 are the same as were applicable to Figure 3, namely, that the movement of the combustion zone is at a velocity of one foot per day. The curve **26**, labeled "zero days," is the vertical temperature distribution as a function of distance above or below the fracture immediately following the passage of the combustion zone. It is apparent that beyond about 5 feet in a typical reservoir stratum, the temperature rise is negligible at this time. The dashed-line curve **27**, labeled "one day," is the coresponding temperature distribution one day later. It is apparent here that a major drop in temperature has occurred at the fracture, but the temperature rise more than 8 feet away from the fracture is practically negligible.

The solid-line curve **28**, labeled "ten days," is the temperature profile after that interval of time, and, as is apparent, a substantial transfer of heat has now taken place to distances of the order of 10 feet or so. The dotted-line curve **29**, labeled "100 days," shows that over this interval of distance and time the temperature has become approximately uniform. This means also that a substantial amount of heat has been lost to the adjacent formations and that the major portion of the recovery of oil should have occurred before this time.

As an example of the operation of our invention, it may be assumed to a first approximation that, if heat losses can be neglected, approximately 0.4 cubic feet per day of a stoichiometric mixture of air and fuel gas should be supplied to each linear foot of fracture zone moving at a propagation rate of one foot per day, for each degree of temperature rise and each foot of formation thickness. Thus, if a recovery operation in accordance with this invention is being carried out on a five-spot well pattern and 10-acre well spacing, with an output well at the center of a square and four input wells 660 feet away at the corners of the square, a simple calculation utilizing this factor will provide a minimum value of gas input rate at any time during the operation. It is only necessary to multiply together four numbers, one of which is this factor of 0.4, and the product obtained is the minimum number of cubic feet per day of input air and fuel-gas mixture that must be supplied.

Thus, when a combustion front has progressed about half the distance of a 660-foot well spacing in a five-spot pattern, so that the length of the combustion front is approximately 2,000 feet, if the zone is 30 feet in thickness and is to be heated 200° F. in temperature above the natural level, then the volume of input gas mixture in cubic feet per day is simply $0.4\times30\times200\times2{,}000$, which is about 4.8 million cubic feet per day, assuming that the velocity of propagation is controlled to about one foot per day. Preferably such a formation would be penetrated by several fractures about equally spaced apart vertically by intervals of 5 to 20 feet in thickness.

If the velocity is controlled by inert gas or liquid injection to a value other than one foot per day, then a corresponding adjustment may be made in the input gas rate. For example, if the propagation velocity is only 0.5 foot per day, then the input combustible gas rate similarly should be divided by two, to become 2.4 million cubic feet per day.

Depending on the number and spacing of the fractures in the producing formation, this minimum input gas rate may be somewhat increased in an actual case to allow for heat losses to adjacent strata and to insure that all portions of the formation are heated to at least a certain minimum extent. In general, the closer together the fractures are spaced relative to the entire thickness of the stratum **10**, the closer the input gas rate can be to the minimum value. This is because with closer spacing the heat diffusion from the fractures to the intervening reservoir rock medium takes place in a relatively shorter length of time, the oil in place is more quickly recovered, and in this time interval a smaller proportion of the heat generated is lost to the adjacent formations.

It is within the scope of this invention to alter the gas content of the reservoir stratum **10** before initiating combustion by first holding back pressure on the output well **12** while gases are being injected into the input well **11**. These gases flow along the fractures **15**, **16**, and **17** with relative ease and from them permeate the stratum **10** over a wide area. In part, the gas may go into solution in the oil, and when heat is subsequently generated within the fractures in accordance with the invention, this additional gas saturation within the oil in place, along with such gas saturation as naturally occurs in the oil, results in substantially increased breakout of gas and formation of bubbles within the reservoir rock medium. This substantially increases the forces available to move the liquid oil, with its viscosity lowered by heating, to the fracture and to the output well **12**, or directly to the output well through the reservoir rock.

By initiating combustion at a relatively high level of static formation pressure and by lowering this pressure during the recovery process, a substantial increase in percentage of oil recovered is often obtainable, especially in the case of low gas saturation oils. The energy added to the reservoir oil by increasing the initial static pressure and gas saturation therein is largely recovered by the additional breakout of gas and the gas drive which takes place upon the occurrence of heating. This is generally a quite efficient way to utilize the driving energy of gas—much more so than merely circulating gas through the formation from an input to an output well to entrain or drive liquid through the rock pore spaces by gas flow alone.

While we have thus described our invention in terms of the foregoing embodiment and specific details, it is to be understood that other and further modifications will be apparent to those skilled in the art. The invention therefore should not be considered as limited in scope to the specific details set forth, but its scope is properly to be ascertained by reference to the appended claims.

We claim:

1. In a method of recovering a high viscosity oil from an underground producing formation in which it occurs, wherein heat is generated by combustion within said producing formation, the improvement which comprises the steps of drilling at least two spaced wells into said formation, one of said wells being an input well and the other of said wells being an output well; initially providing at least one generally horizontal fracture extending continuously through said formation between said wells, said fracture having a gas flow capacity which is large compared to the gas flow capacity of said formation without said fracture; thereafter initiating combustion at the depth of said formation within the bore of said output well; injecting a cool combustion-supporting gas through said input well to flow primarily through said fracture to support said combustion and to propagate a zone of combustion chiefly along said fracture back toward said input well; controlling the composition and injection rate of said combustion-supporting gas so that the equivalent of at least about 0.4 cubic foot of a stoichiometric mixture of air and gaseous fuel is consumed per foot of length of said zone, per foot of propagation, per foot of thickness of said formation, per degree F. of temperature rise necessary to reduce the viscosity of said oil to a predetermined level where it will flow easily to said output well, whereby the major portion of the heat generation takes place in said fracture, and the oil in said formation above and below the combusion zone in said fracture is heated primarily by the heat diffusing generally vertically through said formation from said fracture, and whereby the temperature of most of said oil remains substantially below a level where cracking takes place; and recovering from said output well the oil which is released from said formation by said diffusing heat and which enters said output well.

2. In a method of recovering a high viscosity oil from an underground producing formation in which it occurs, wherein heat is generated by combustion within said producing formation, the improvement which comprises the steps of drilling at least two spaced wells into said formation, one of said wells being an input well and the other of said wells being an output well; initially providing a plurality of generally horizontal fractures extending through said formation continuously between said wells and through the area of said formation surrounding said wells, said fractures being spaced through said formation at approximately uniform intervals of depth of between about 5 and 20 feet, the lowermost of said fractures being near the lower boundary of said formation, and the flow capacity of said fractures for gas being large compare to the gas flow capacity of said formation without said fractures; thereafter initiating combustion at the depth of said formation within the bore of said output well; injecting a cool combustion-supporting gas through said input well to flow primarily through said fractures to support said combustion and cause zones of combustion to enter and propagate chiefly along said fractures back toward said input well; controlling the composition and injection rate of said combustion-supporting gas so that the equivalent of at least about 0.4 cubic foot of a stoichiometric mixture of air and gaseous fuel is consumed per foot of length of combustion zone, per foot of propagation, per foot of thickness of formation to be heated from each of said fractures, per degree F. of temperature rise necessary to reduce the viscosity of said oil to a predetermined level where it will flow easily to said output well, whereby the major portion of the generation of heat takes place within said fractures, and the oil in place in said formation between and above and below the combustion zones in said fractures is heated primarily by the heat diffusing generally vertically through the formation from said fractures, and whereby the temperature of most of said oil between said fractures remains substantially below a level where cracking occurs; and recovering from said output well the oil which is released from said formation by said diffusing heat and which enters said output well.

3. In a method of recovering high viscosity oil as set forth in claim 2, the step of adding to said combustion-supporting gas a proportion of inert heat-transferring fluid effective to retard the propagation rate of said combustion zones through said fractures so that substantially more than the equivalent of 0.4 cubic foot of a stoichiometric mixture of air and gaseous fuel is consumed per foot of length of the combustion zones, per foot of propagation, per foot of formation thickness to be heated by each zone, per degree F. of temperature rise necessary to reduce the viscosity of said oil to a desired predetermined level.

4. In a method of recovering a high viscosity oil, steps as set forth in claim 3 wherein water is injected along with said combustion-supporting gas as said inert heat-transferring fluid.

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