Sept. 22, 1964

B. F. GRANT

3,149,670

IN-SITU HEATING PROCESS

Filed March 27, 1962

FIG. 1

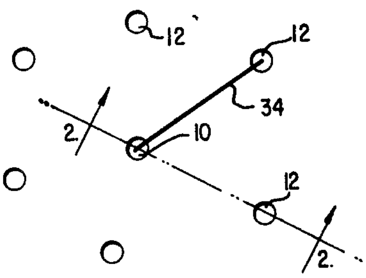
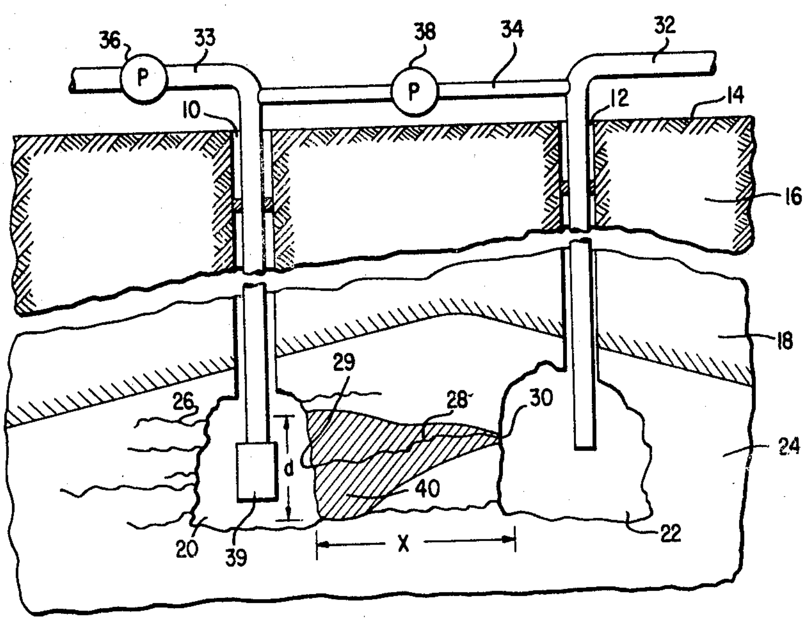


FIG. 2



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IN-SITU HEATING PROCESS

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This invention relates to a method for recovering hydrocarbons from an underground petroliferous formation. Such hydrocarbons are solids or viscous liquids, generally unflowable at ordinary formation temperatures, and may be characterized by having an API gravity less than about 25°. Such a viscosity characterization applies to "solid" hydrocarbons as well. The method is concerned with relatively gas-impermeable formations such as shale, etc. Such formations may have low gas permeability, for instance, due to high liquid saturation with heavy oil or the low permeability may be due to heating the formation, causing heavy hydrocarbons to melt and flow to cooler zones where they condense and clog the formation. Generally the applicable formations have an effective gas permeability of less than about 10 millidarcies.

The process of this invention converts a corridor of reduced resistance to gas flow in the formation between an input well and an output well into a hot passageway and maintains this passageway while hydrocarbons are recovered by thermal means. In the process a large mass of the petroliferous material is heated by conduction from the wall of the input well and the walls of the corridor and the heated zone progresses toward the output well to cause hydrocarbons to move to the passageway and to the output or production well. This invention has the important advantage that after the initial heating and hydrocarbon recovery the formation is susceptible to treatment by other thermal methods of hydrocarbon recovery, such as sweeping out additional hydrocarbons by a moving hot zone, and the process of this invention may include such a procedure.

The recovery of viscous crude hydrocarbon material is important in those areas where such hydrocarbons are, or may soon be, the principal indigenous source of petroleum liquid hydrocarbons or where the cost of finding and producing crude petroleum has risen so that the viscous oils and other non-flowable hydrocarbons can be recovered and refined on an economically competitive basis. The formation which contains the non-flowable hydrocarbons may be one of a number of types. For example, shale is a fine-grained, compact sedimentary rock having splintery uneven laminae, which may contain about 10 to 65 or more gallons of oil per ton in the form of a solidified, resinous organic material which clings to the siliceous shale particles. In other formations the basic structure may comprise porous rock clogged with non-flowable hydrocarbons, or sand particles having hydrocarbons at the interstices. Such sand formations may be unconsolidated, that is, crumbly in the absence of hydrocarbons, or consolidated.

Although quarrying and surface retorting of shale is practiced in some places to recover hydrocarbons, removal of the overburden or mining in many areas is generally impractical. Also, the use of heat in situ to fluidify, that is, to melt, distill or decompose the non-flowable hydrocarbons is not always a panacea. In such "secondary" recovery methods, with one or more input and one or more output wells drilled through the overburden and the hydrocarbon-bearing formation, a high temperature may be established in the input well by lighting a fire there, or using an electric heating element or other heating means. The entire formation may be heated at least to the fluidifying temperature of the hydrocarbons which then drain out to the production well or wells. However, such a conduction process is expensive since the whole formation must be kept heated, usually by burning saleable fuel, and a good deal of heat is wasted to the overburden and the substrata. Further, these heating methods generally require the output well to be rather close to the input well. A distance of less than about fifty feet between input and output wells is undesirable from an economic standpoint since the closer together these wells are placed the closer the drilling and equipment cost would come to the cost of removing the overburden completely. This conduction method would not be readily adapted to such wide well spacings. The creation of fractures in the shale or other tight formation allows for better drainage of fluidified hydrocarbons, but the conduction method of heating the entire formation would still waste heat and would not clean sufficient of the hydrocarbons from the formation. Methods are known for creating fractures in underground petroliferous strata and are described for example in U.S. Patent Nos. 1,422,204; 2,584,605; 2,630,306; 2,630,307; 2,780,449 and 2,813,583.

An alternative type of secondary recovery process involves forcing a hot gas through the formation to heat the formation largely by convection and to both fluidify and clean out the hydrocarbons. The hot gases, generally supplied by a fire in the input well or by burning materials in the formation itself, are brought into contact with the non-flowable hydrocarbons throughout the stratum. This type of process also wastes a great deal of heat in keeping the formation hot after substantial removal of hydrocarbons from one zone of the formation while the hydrocarbons have yet to be recovered from other zones spaced farther away from the input well. Also, and perhaps most importantly, most formations containing heavy crude hydrocarbons having a gravity less than 25° API have low gas permeability, requiring increases in gas pressure for application of these convection heating processes. Such formations frequently have a "natural" gas permeability less than about 10 millidarcies or even less than about 5 md., for example, less than about one md. Although the gas permeability of such formations may be improved by using the fissuring techniques mentioned above, the application of heated gas under pressure sufficient to penetrate the formation usually will cause the heavy hydrocarbons, having an API gravity less than about 25° to melt and flow to cooler zones where they condense and clog the formation. This phenomenon may occur also in formations, having relatively good original gas permeability, which contain such heavy hydrocarbons.

In many of these formations therefore, secondary recovery methods which involve gas circulation are impossible due to the extreme gas pressures required, which in some cases would lift the overburden, and which in all cases would require a great deal of expensive power to produce the needed gas pressure. Even more pressure is needed when the input and output wells are far apart, and closer drilling has the disadvantages outlined above. Thus it may be uneconomical to work, by gas heating, a heavy crude-containing formation with a fairly high original specific permeability, say 2 to 3 darcies. Even though a hot, pressured, gas technique applied to such a formation manages to preserve a corridor of 50 millidarcies permeability, the cost for gas compression may still be greater than the value of the recovered hydrocarbons.

The waste of heat encountered in the secondary recovery methods outlined may, to some extent, be overcome by the "burning wave" method of sweeping out the formation, disclosed in U.S. Patent 2,780,449 to Fisher et al. In this process, after fracturing is performed where necessary, the zone around the input well bore hole is heated to liquefy and decompose the non-flowable hydrocarbons by burning fuel gas at the bottom of the well. High gas pressure is used to drive liquefied or volatilized hydrocarbons through the formation and toward the output well and when the temperature in the formation surrounding the input bore hole gets high enough to cause combustion of the carbonaceous residue of the formation, the fire is transferred to the residue in the surrounding deposit by extinguishing the bore hole fire and forcing combustion supporting gas into the well. This cools the input well and the fire or heat assumes the form of a relatively narrow "burning wave," liquefying and volatilizing hydrocarbons ahead of it and burning the carbonaceous residue. The zone behind the burning wave is cooled by the continual flow under pressure of combustion supporting gas which can be diluted or alternated with inert gas. The gas in turn is warmed by the time it reaches the burning front, further conserving heat. The savings in fuel costs in this method are obviously great since frequently only the fuel for the initial bore hole fire needs to be supplied from extraneous sources and unrecoverable solid carbonaceous material in the formation serves in whole or in part as the fuel after the burning zone is transferred to the formation.

However, the problem of having to create high gas pressures in order to drive forward the hot zone through the entire formation is not obviated in this system which simultaneously heats and purges zones in the formation remote from the input well, with the result that liquefied or vaporized hydrocarbons from the first hot zone are sent through unheated zones in the formation on the way to the output well. Passage through these zones condenses and congeals the hydrocarbons inside the fractures or other passageways in the unheated zone, clogging the fractures and increasing the pressure required to maintain flow of these hydrocarbon and exhaust gases to the output well. The pressures needed to obtain substantial gas flow may increase to the point where the process is not practical. Although the passage of fluidified hydrocarbons through a cold formation which tends to congeal these materials may be avoided to some extent by having the burning wave travel along a fracture from the output well to the input well, such a procedure, as described for example, in U.S. Patent 2,901,043 has some serious shortcomings. When relying upon heating and gravitation alone, recovery of oil is low from impermeable formations adjacent the fracture. Also, such a burning wave would consume as fuel a quantity of the more volatile hydrocarbon materials, substantially reducing the recovery of the most sought-after constituents of the formation.

The present invention obviates many disadvantages of these processes by providing a hot passageway; that is, at least a partly heated formation and a heated corridor for flow of the liquid and vaporous hydrocarbons from the formation during initial heating and during the travel of a subsequent sweep gas or a burning wave through the preheated formation, preventing deposition of the hydrocarbons in the hot passageway in a state that inhibits flow to the production well and, if desired, using nonrecoverable constituents as the primary fuel source in the burning wave treatment. The formation of the hot passageway may be preceded by the formation of one or more corridors of low gas resistance through a formation where no corridor exists and can be followed by gas sweeping or moving a burning wave through the heated formation to take remaining hydrocarbons toward the production well. The corridor of high gas permeability will have less resistance to gas flow than the remainder of the formation and will in general have a gas permeability greater than about 1 darcy. The minimum permeability required of the corridor may vary with the circumstances but in any event the corridor must have sufficient permeability to allow passage of gases without needing a pressure high enough to lift the overburden. The corridor must have a permeability different enough from the rest of the formation that a pressure can be imposed upon gases in the input well which will allow passage of the gases through the corridor without substantial passage of the gases through the formation. In other words the corridor is a part of the formation stretching continuously from input to output wells through which gases in the input well pass to the output well in preference to passing through the formation in general. During production of the hot passageway, the invention uses insufficient pressure to move injected or exhaust gases into and through the cold portions of the formation other than the corridor.

Where a formation containing viscous crude hydrocarbon does not have a "natural" corridor of low gas resistance, such as a crack or fissure, such may be created between output and input wells by horizontal drilling but preferably is done by fracturing the formation. Fracturing may be brought about by pumping quantities of gases, heated if desired, or liquids into the input and/or output wells and increasing the pressure until seams or fissures of the desired fluid flow capacity have been opened in the stratum. This invention requires that a fracturing step when applied to a relatively impermeable formation results in the opening of at least one substantially continuous fracture between the input and output well. This corridor, which is later converted to the hot passageway, serves as the core or axis for the hot passageway. This corridor provides a path of substantially diminished resistance to fluid flow between the input and output wells and must be sufficient to conduct hot fluids into contact with the formation and to carry gaseous or liquid hydrocarbons to the output well. If desired, the corridor may be propped open with sand or other granular solids which do not prevent fluid flow to the output well. It is to be understood that the corridor is sufficient to provide only a small fraction of the fluid-carrying capacity of the entire stratum.

The creation of the hot passageway along the continuous corridor between the input and output wells can better be understood by reference to the accompanying drawing in which:

FIGURE 1 represents part of a field having a subterranean formation or stratum which contains viscous hydrocarbons; and

FIGURE 2 is a cross-sectional view of part of the field with a representation of a possible shape of the hot passageway.

In the drawings input well **10** and several output wells **12**, have been drilled into the ground **14**. The wells penetrate strata of overburdens **16** and **18** and effectively terminate in bottom holes **20** and **22** in the input and production wells, respectively, and have their ends in the stratum **24** which contains the non-flowable hydrocarbon material. A fracturing process, in which pressure has been applied from the input well **10**, has produced fissures **26**, in the stratum, **24**. At least one of these fissures, the corridor **28** extends from the opening **29** in the bottom hole **20** of the input well **10** to an exit **30** in the bottom hole **22** of an output or production well **12**. The output and input wells are fitted with pipes **32** and **33**, respectively, for the travel of gases and the output wells may have means such as a pump (not shown) for recovering liquid hydrocarbons. The conduit **34** is provided for recycle of gases and pumps **36** and **38** provide the gas pressure necessary for circulation through the corridor **28**. Since the work required in pumping a gas is proportional to the difference in the squares of the initial and final absolute pressures; i.e., $Q=K(P_1^2-P_2^2)$ (see, for example, Perry, Chemical Engineers Handbook, 3rd ed., 1950, page 302), less work is generally required to bring about a given pressure difference when a higher initial pressure brings this difference closer to 0. For this reason, the pressure in the output well is preferably maintained above atmospheric pressure and usually at a minimum of about 200 p.s.i.g., with the maximum being somewhat below that pressure which would lift the overburden. The pressure in the input well during the creation of the hot passageway need only exceed the pressure in the output well by just sufficient pressure to bring the fuel and combustion supporting gases from the input well through the corridor **28**. This difference in pressure of input well gases over output well gases is insufficient to cause significant gas flow through portions of the stratum other than the corridor. In this way, compression costs for injected gases can be reduced.

In a preferred embodiment of this invention a fire is maintained in the bore hole **20** by burning a fuel gas therein after corridor **28** is formed. The ignition and maintenance of the fire may be performed by conventional burner means **39** and the temperature of the fire is allowed to increase to at least about 700° F. The bore hole temperature can be maintained at this minimum level by regulating the proportions of fuel gas and combustion supporting gas sent through the pipe **33**. The heat in the bore hole may exceed 700° F. up to a temperature where the casing or bore hole wall of the input well **10** may be damaged, but the temperature of the formation adjacent the input bore hole will usually not be greater than about 1500° F., frequently not greater than about 1000° F. As mentioned above, during the heating only enough gas pressure is applied to the input gases to get them in sufficient quantity to the bottom hole **20** and through the corridor **28** to the output well. In travelling through the passageway the gases may pick up additional fuel components from the adjacent formation and so may be recycled back to the input well through the conduit **34** to exploit this fuel value and the heat of the exhaust gas. Alternatively the exhaust gases may be passed in a direct or indirect heat exchange relationship with the input gases to conserve heat.

The fire in the bottom hole **20** heats the walls of the input well and the walls of the corridor **28** become heated by moving gases. Heat is transmitted primarily by conduction from these heated walls into the formation, and gradually a zone in the formation adjacent the walls of the corridor **28** will become heated. This heated zone is shown in the drawing as shaded area **40**. The form of conduction by which this heated zone **40** is created is described in Perry, Chemical Engineers Handbook, 3rd ed. (1950), p. 458. The gases moving through the corridor **28** are, of course, cooled by contacting the walls of the formation, so that it takes some time for the heated zone or hot passageway **40** to reach a temperature of at least 700° F. all the way from the input well to the output well.

The conduction of heat into the stratum which takes place from the walls of the bottom hole **20** and the walls of the corridor **28** heats up a passageway having a smaller transverse cross-section as it approaches the bottom hole **22** of the output well **12**. Thus the longitudinal cross-section of the passageway may assume the shape of the shaded area **40**. Heating under mild gas pressure is continued until a heated zone, i.e., a mass of formation having a temperature of at least about 700° F. is created which extends for at least about 40 or 50 feet along the vertical wall of the bottom hole **20** and this 700° F. isotherm may even extend the complete height of the hydrocarbon-containing stratum. The heating may raise the temperature of the entire stratum between the input and output wells, and it may be continued until essentially all of the stratum between the input and output wells is heated to the required minimum temperature, but this is usually neither necessary nor desirable. The approximate 700° F. minimum temperature is sufficient to fluidify, that is, to liquefy and/or vaporize hydrocarbons in or recoverable from the formation. As the heat of the walls of the borehole and the walls of the fracture is transmitted to the surrounding formation, the kerogen or

other petroliferous material contained in the heated zone is affected and the heat thus serves gradually to remove a certain amount of hydrocarbons from the zone, which are conducted by the corridor to the output well for recovery. Since the creation of the hot passageway is carried out under the minimum gas pressure and since the corridor provides much lower resistance to the passage of gas than the body of the formation, there is little penetration of heated hydrocarbons into cold portions of the formation during heating. As hydrocarbons are removed from adjacent the corridor to the production well, the permeability of the heated zone is increased creating a passageway for gases. When a later gas sweep or burning wave treatment, conducted under substantially increased gas pressures, is applied to this formation, the hydrocarbon materials which are taken from the formation can travel to the output well without being exposed to congelation temperatures and, therefore, without clogging all passageways and requiring uneconomically high pressures for the creation and maintenance of gas circulation.

The shape of the heated zone is determined by the characteristics of the fractured formation, for example, the specific heat of the formation material and the convective ability of the corridor or continuous fracture, **28**. The same factors, as well as the ignition temperature of the fuel, will also determine how high a temperature above about 700° F. may be reached in the heated zone. The time required to heat the formation to create a base for the passageway at the wall of the input well bottom hole having the desired 700° F. temperature and at least about 40 or 50 feet in diameter also depends upon how much heat is consumed in fluidifying the hydrocarbons of the formation. The rate of gas injection and the composition of the injected gases govern to a large extent the amount of time taken for the complete length of the fracture to reach the desired temperature.

A mathematical formula can be developed for determining the amount of time during which burning is continued in the bottom hole in the input well under a minimum gas pressure differential between input and output wells before increasing the pressure, changing the composition of the input gas to cause burning to take place in the formation, if this latter operation is to be undertaken and plugging the original corridor to prevent bypassing, if necessary.

Assuming that the heat source in the input bottom hole heats directly to a temperature of at least about 700° F. a more or less circular area on the wall of the bottom hole which includes the opening **29**, this directly heated area may be assigned the diameter d_o. If s represents the rate of heat transfer by conduction through the shale, t_s, the time during which low pressure heat is applied to the formation to extend the 700° F. isotherm to the diameter d will equal

$$\frac{d-d_o}{2s}$$

The time t_u required for the complete fracture to be heated, is given by the formula:

$$t_u=\frac{x}{u}$$

where x is the length of the fracture from input to production well and u is the rate of heat transfer by convection through the fracture. The heating of the bottom hole of the input well is preferably continued at least until the 700° F. isotherm reaches the output well in which case the time of low-pressure heating is at least about t_s or t_u, whichever is larger. Heat conservation, however, might preferably dictate that the distance x between input and output wells be chosen so that $t_s=t_u$. The essential capacity of the hot passage for conducting gaseous products is determined to a large extent by the cross-sectional area of the passageway at its narrowest point, which may be at the output well end of the passageway. The most practical capacity depends upon many physical and economic factors, but usually it will be desired to continue low pressure heating until the 700° F. isotherm extends for some distance along the wall of the output well around the exit of the corridor into the output well. Heat is transmitted into these remote zones of the stratum by conduction from the wall of the fracture.

During conduction heating the pressure used to force input gas into the well, as mentioned above, is preferably the minimum required to maintain combustion in the bottom hole and is insufficient to force gas through unfractured portions of the stratum or fractures which do not closely approach the output well. This pressure need only exceed slightly the total pressure caused by the weight of the column of gas in the output well, the frictional losses in the fracture and the updraft of flue gases in the input well. The pressure to be applied may be reduced below this figure when aided by strong convective currents in the fracture and up the output well due to gas expansion from heat and due to the vaporization of hydrocarbons in the formation. In any event, the pressure applied to the input gases need only be enough to secure sufficient gas circulation to bring the fuel and combustion supporting gas to the region of combustion and carry the gases up the output well, which is preferably under superatmospheric pressure.

The heated passageway is maintained at a temperature of at least about 700° F. during a subsequent hydrocarbon recovery procedure which employs passage of gas from the input well, through the preheated formation or passageway, and to the output well at a pressure higher than employed in creation of the heated passageway. In order to insure flow of the gas through the formation itself, rather than through the generally more permeable, original corridor, the end of this corridor adjacent the input well may be plugged, to a greater or less extent, depending on the relative permeability of the corridor and the adjacent heated zone of the formation.

A simple way to recover hydrocarbons from the formation is the injection of a gas into the formation from the input well to fluidify hydrocarbons in the formation. This sweep gas, preferably at a temperature of at least about 700° F. and, of course at a pressure sufficient to penetrate the formation itself, travels through the hot passageway and maintains the passageway at this temperature. The passage of the gas may also serve gradually to heat zones in the formation surrounding the hot passageway to the approximate 700° F. mark causing fluidification of the hydrocarbons contained therein. Liquid hydrocarbons drain from newly heated zones into the hot passageway and travel to the output well; vaporized hydrocarbons are entrained in the sweep gas and may be separated therefrom at the production well exit. Gradual removal from the formation of the hydrocarbons, combined with heating of the formation, serves to enlarge the cross-sectional area of the hot passageway as zones, remote from the corridor and from the input well, increase in their temperature and gas permeability. The composition of the sweep gas is not too important, but preferably it is a non-combustion-supporting gas such as flue gas or steam.

Alternatively, after the hot passageway and heated formation are established and the corridor plugged, if necessary, a moving burning wave can be generated in the previously heated formation, for instance, according to the process of the aforementioned U.S. Patent No. 2,780,449. As an example, the proportions of fuel gas and combustion supporting gas sent to the fire in the bottom hole of the input well are adjusted, if necessary, to give a temperature level in a portion of the formation of at least about 700° or 1000° F. or higher depending on the combustion temperature of the carbonaceous residue in the siliceous material in the vicinity of the input well bore hole. The

pressure is increased to a value sufficient for the combustion gases to penetrate at least the portions of the formation which have been heated by conduction. The gas flow rate should be as high as is practical at a pressure sufficient to maintain passage through heated portions of the formation from the input well to the output wells or output zone. When the heated zone, that is, a zone having a temperature of at least about 700° F., has been established at the wall of the input well, burning in the input well is discontinued and the heated zone is moved as a thermal front or wave radially outward into the formation through the area preheated by conduction and in the direction of the output well. This can be performed by substituting an unheated substantially noncombustible oxygen-containing gas stream for the fuel-gas-air mixture so that the region of peak temperature is moved gradually outward into the formation and the input gas flow continues at a high rate in conduit **10**. In this manner the injected gas stream is an effective heat transfer medium absorbing heat as it approaches the peak temperature region of, for example 700 to 1000 or 2000° F., and transferring heat absorbed in the process to the regions of the formation beyond the hot zone. Gases, both those injected and those produced by heating, and fluidified hydrocarbons flow through the heated passageway **40** to the output well. The pressure on the input gases may force some of the heated gases into unheated zones within the formation to secure recovery of hydrocarbons from these zones or these zones may be heated by conduction in advance of the burning wave. Thus, the hot zone is moved as a front or thermal wave from the input well region through the preheated formation toward the output well. During the operation, or as part of a coordinated cycle, the temperature level is maintained in the frontal zone by controlling the oxygen content of the input gas with water, recycle flue gas or other substantially inert diluents.

A principle behind the moving thermal front formation is the reduction of the fuel content of the input gas stream to a proportion below the explosive limit so that the mixture cannot ignite until it is in the formation where unburned carbonaceous matter is available to enrich the fuel-oxygen ratio to within combustible limits and where a high enough temperature for spontaneous combustion exists. As injection of the cool oxygen-containing gas proceeds, regions in the stratum closer to the input well are cooled while regions remote from the heated passageway may be successively heated to 700° F., a temperature sufficient to fluidify and remove a quantity of the hydrocarbons present therein and to increase the cross-sectional area of the portions of the heated passageway remote from the input well. A carbonaceous residue is left in the passageway as fuel for combustion when the residue is contacted with the oxygen-containing gas.

In order to accomplish continuous forward movement of the heated zone as a wave of relatively narrow profile and high peak temperature, it is advantageous to move the zone into the formation by use of a relatively cool gas drive system. Alternate cycles may be operated in which an inert gas mixture, for example, recycled flue gas substantially free of oxygen, may be employed as a cold gas drive to keep the burning zone confined to the moving front and to heat the formation in front of the burning wave. Usually the combustion supporting gas will contain about 1–25% by volume of free oxygen, preferably about 5–20%.

In certain circumstances, depending on the character of the crude hydrocarbons and the well spacing, a reverse burning wave procedure may be advisable. For example, where the input well is rather distant from the output well and where heating of portions of the formation results in the movement of great amounts of viscous crude to the hot passageway at a temperature below about 700° F. thus tending to cool and clog the passageway, it is feasible to conduct the burning wave in reverse, that is, to have it pass from the producing well back to the input well, as disclosed in the aforementioned U.S. Patent 2,793,696. This reverse-traveling wave front may be accomplished by heating the walls of the output well, after the creation of the hot passageway, to combustion temperature and passing combustion-supporting gas into the output well until combustion is established in the formation adjacent the output well. When combustion is thus established in the formation itself, injection of combustion supporting gas to the output well is discontinued while injection of this gas into the input well at a relatively high pressure and exhaustion of the waste and hydrocarbon-containing gases from the output well is established. The creation of the hot passageway can overcome some of the difficulties encountered with reverse-burning waves described in the above-mentioned patent. During the burning wave, the hot passageway will offer less resistance to the flow of combustion-supporting or waste gases and also will, partially at least, provide for hydrocarbon recovery in the part of the stratum near the input well which may be beyond the economic recovery limit of the reverse-wave treatment.

As mentioned previously, the greater proportion of gases pass through the previously heated passageway which is maintained at a temperature above the congealing temperature of the fluidified hydrocarbons. The gases carry with them the vaporized hydrocarbons to the production well. Liquid hydrocarbons also flow to this well and recovery from the well may be accomplished by any suitable means.

Sometimes it may be desirable to introduce cool combustion supporting gas and perhaps some fuel gas as well to the output well when a burning wave breaks through to the production well. Such a procedure serves to cool the production well and also perhaps to prevent combustion of liquid hydrocarbons which have drained to the production well bottom hole. The cooling of the production well is desirable to prevent destruction of equipment in the production well and the plugging of the bore hole or equipment by coke and soot accumulation. Water may also be injected into the output well to control combustion and also, by partially filling the bottom hole, to prevent pressure escape to other parts of the field.

It is thus seen that the initial heating method of this invention removes hydrocarbons from an underground deposit containing hydrocarbons in a substantially nonflowable condition while minimizing heat losses and gas pressure requirements. For example, when applied to shale or a Kansas field containing a crude oil of about 23° API and exhibiting an effective gas permeability of 3 md., the method of this invention gives better results than other secondary recovery methods. The process prepares the formation for treatment by subsequent gas sweep thermal recovery procedures. The latter procedures include more gas sweeping the preheated formation or sending a burning wave through the stratum.

This is a continuation-in-part of copending application Serial No. 631, filed January 5, 1960, and now abandoned.

It is claimed:

1. In a method for recovering hydrocarbons having a gravity of less than about 25° API from an underground formation containing such hydrocarbons and having an effective gas permeability of less than about 10 millidarcies containing a first well, a second well, and a corridor of reduced resistance to fluid flow as compared to the rest of the formation and reaching from the first to the second well, which comprises heating the formation of the first well to a temperature of at least about 700° F. by combustion of a fuel gas in the first well under a pressure sufficient to pass exhaust gases through said corridor and up the second well, but insufficient to drive a substantial amount of gases through other portions of the formation, said heating being continued until a zone heated to at least about 700° F. is created extending through the corridor to the second well and for at least about 40 feet along the bore wall of said first well to heat by conduction to a temperature of at least about 700° F. the formation adjacent said corridor, and passing a gas under increased pressure through said heated zone adjacent the formation to recover hydrocarbon materials therefrom.

2. The process of claim 1 where the permeability of the formation is less than about 5 millidarcies.

3. The process of claim 1 where the formation is shale.

4. The process of claim 1 where the corridor has a permeability greater than about one darcy.

5. The method of claim 1 in which the heated zone is heated to a temperature of about 700–1500° F.

6. The method of claim 1 in which the heated zone is heated to a temperature of about 700–1000° F.

7. The method of claim 1 in which the heated zone has a smaller transverse cross section at the part near the second well than the part near the first well.

8. In a method for recovering hydrocarbons of less than about 25° API gravity from an underground formation containing such hydrocarbons and having an effective gas permeability of less than about 10 millidarcies and containing a first well and a second well, the steps comprising fracturing the substantially impermeable formation between the first well and the second well to obtain a corridor extending from the first well to the second well and having a gas permeability greater than about one darcy, heating the formation of the first well to a temperature of at least about 700° F. for a vertical distance of at least about 40 feet by combustion of a fuel gas in the first well under a pressure sufficient to pass exhaust gases through said corridor and up the second well, but insufficient to drive the exhaust gases through unfractured portions of the formation, said heating being continued until a zone heated to at least about 700° F. is created extending through the corridor to the second well, and passing an oxygen-containing gas into said heated formation from said first well under an increased pressure to establish combustion in said heated formation and continuing the injection of oxygen-containing gases to move said combustion in the heated formation towards the second well to facilitate the recovery of hydrocarbons from said formation.

9. The process of claim 8 where the formation is shale.

10. The method of claim 8 in which the heated zone is heated to a temperature of about 700–1500° F.

11. The method of claim 8 in which the heated zone is heated to a temperature of about 700–1000° F.

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