METHOD OF PETROLEUM PRODUCTION BY FORWARD IN SITU COMBUSTION

FIG. 1.

FIG. 2.

FIG. 3.

INVENTOR:

WILLIAM C. HARDY

BY

ATTORNEYS
METHOD OF PETROLEUM PRODUCTION BY FORWARD IN SITU COMBUSTION

William A. Hardy, Richardson, Tex., assignor to Sun Oil Company, Philadelphia, Pa., a corporation of New Jersey

Filed Nov. 2, 1962, Ser. No. 235,628

3 Claims. (Cl. 160—11)

This invention relates to a method for recovery of hydrocarbons from oil-bearing formations, and has particular reference to recovery processes involving in situ combustion.

Recovery of hydrocarbons by the use of in situ combustion procedures is known, there being two classes of such procedure involving, respectively, forward or backward burning. The present invention is concerned with the forward burning procedure.

In the procedure, the petroleum-bearing formation from which recovery is sought is penetrated by one or more injection wells and one or more production wells suitably drilled in what appears from prior knowledge of the formation to be optimum locations. The procedure involves injection of air into the injection well or wells, the initiation and maintenance of burning starting at the injection point, and the collection of the resulting product from the producing well or wells. Particular procedures for carrying this out are well known and need not be described in detail. The combustion process is used usually as a secondary recovery process, may be used when other procedures have failed either to initiate or continue production. For example, due to its geologic history, some beds e.g. tar sands, may, when first located, contain only, or largely, highly viscous and non-volatile hydrocarbon residues which cannot be made to flow by ordinary methods. In other cases, more conventional methods may have been used to remove more mobile and volatile constituents leaving residually in the formation pores residues which are so viscous as not to flow or which are in such quantities as to be held by wetting of the rock constituents without existing in a continuous liquid phase.

To attack these and similar conditions, the burning process is used, which consuming some of the hydrocarbon residues, provides heat which cracks other portions of the residues producing gaseous and/or liquid products which will flow to the production point.

In the combustion process, however, a difficulty arises due primarily to the condensation of water arising from the combustion of hydrocarbons or, more generally, from both this and vaporized interstitial water. This water, existing as steam where a temperature is sufficiently high, is condensed further on in progress through the formation where temperatures are sufficiently low considering the existing pressure. This water has the well-known Jamin effect producing viscous blocking in the zone of condensation. This viscous blocking retards the flow of air and all other fluid materials in the various zones involved in the process, and seriously impairs the performance of the process.

It is one object of the present invention to provide a production procedure, which, taking advantage of temperature and pressure variations, will reduce the blocking action and permit the reestablishment of normal operation. It is found, further, that the procedure in accordance with the invention has additional advantages in making use, for drive purposes, of both gases changed from liquid phase and gases dissolved in the liquids, both oil and water, in the condensation and subsequent zones. A further object of the invention is to provide a procedure taking advantage of this situation.

Further objects of the invention relating to details, as well as the attainment of those already described, will become apparent from the following description, read in conjunction with the accompanying drawing in which:

FIGURE 1 is a diagram, in the form of a vertical section illustrating a portion of an oil reservoir to which the invention is applied;

FIGURE 2 is a plot of temperature versus distance, explanatory of aspects of the operation and

FIGURE 3 is a static pressure versus temperature chart further explanatory of the invention.

Referring first to FIGURE 1, one or more injection wells are indicated at 2, provided with control valves 4, and penetrating at their lower end 6 a hydrocarbon-containing formation indicated at 8. Spaced from these are production wells 10 illustrated as provided with control valves 12, which wells penetrate the same formation at 14. It will be understood that while these wells are merely diagrammed, they may be provided in accordance with well-known practices which need not be described in detail, having no bearing on the essential novel, burning aspects of the invention. The production wells may, of course, be pumped if required. The wells are also relatively located in accordance with conventional good practices depending upon the knowledge of the producing formation, this knowledge being secured by preliminary conventional exploration, by the drilling of test holes with core sampling, etc. In brief, the arrangement adopted is to secure, ultimately, maximum recovery with minimum cost. It might be stated, as a summary, that the locations are such as to secure a sweeping of desired products from a maximum region consistent with the adoption of the forward burning procedure.

Considering the wells indicated in FIGURE 1, the formation between the injection well or wells and the production well or wells, contains identifiable zones though the boundaries of transition from each zone to the next may not be sharply defined; in fact they may be quite indefinite. These zones, in sequence, are a burned zone 16, a combustion zone 18, a cracking zone 20, a condensation zone 22, and an unaltered zone which, for reasons which will become apparent later, is somewhat arbitrarily illustrated as having two portions 24 and 26, quite indifferently differentiated.

As the production with burning proceeds, these zones shift from left to right, as viewed in FIGURE 1, and the positions illustrated are merely arbitrarily shown both as to location and extent, both of these matters varying with time and in dependence on the formation and its contents as well as its surroundings.

Considering the zones individually, there is first the burned zone 16 which, after progress of the procedure, will surround each injection well and later probably surrounds, as a single zone, all of a group of injection wells. This burned zone will generally be devoid of, or quite low in content of, combustible material. Surrounding this zone 16 in the direction of flow through the formation is a combustion zone 18, and beyond this also in the direction of flow is a cracking zone 20. In considering these zones, the progress and results of the combustion may be described. Initial burning in a particular region may involve the combustion of substantial amounts of the volatile hydrocarbon contents. The generated heat produces cracking, however, and the resulting volatile constituents are, to a considerable extent, vaporized passing off as hydrocarbons in the combustion products. This cracking produces coke, which, at the high temperatures involved, burns. Accordingly, as the combustion procedure goes on, the residual coke is the burning material primarily involved in the combustion zone such as 18 and in view of the relatively large quantities of this which accumulate, the greater part of the oxygen in the injected air is utilized in burning this coke to carbon monoxide and dioxide, producing, to flow
from that zone, hot gas, largely consisting of nitrogen, carbon monoxide and carbon dioxide, with some water remaining from the burning of hydrocarbons, which hot gas will not support further combustion. It is the heat of this gas which cracks the carbonaceous materials in the subsequent cracking zone in which oxidation is at a minimum, resulting in the production of volatile hydrocarbons which react together with the formation of coke which is later burned as the combustion zone progresses.

From the standpoint of the present invention, the next zone, condensation zone 22, is of special significance. Pressures involved in both the combustion and maintenance of flow, during the active part of the combustion-cracking procedure, are such that steam and water, and at relatively non-volatile hydrocarbons are condensed due to the lower ambient temperature of the formation. As a result, there exists the zone 22 in which such condensation occurs. The condensed water originates, in part, because, while coke is the primary burned material, there is always some substantial burning of hydrocarbons, particularly in the initial stages of the procedure. Additionally, there is condensed water which originated as interstitial water and which in a preceding region was volatilized. It will be evident that this accumulation of water condensate is cumulative, the condensation zone as it moves, not only containing water from its previous location, but also added water resulting from combustion and further progressive volatilization of the interstitial water. Thus a point is reached where the water concentration becomes quite high.

At the same time, hydrocarbons are condensed, and this also is a cumulative phenomenon.

The ultimate result is that the condensed water gives rise, by Jamin effect, to a blocking condition which restricts liquid permeability and also to a reduced gas saturation restricting gas permeability. The result is the production of a blocking action which inhibits flow to such an extent that the desired, acceptably active, results of the combustion are no longer secured.

The temperature in the condensation zone will, in general, be close to the condensation temperature of water at the pressure involved. This temperature will range well above 212°F., depending upon the pressure on the system.

Water condensation has so far been primarily considered. Hydrocarbon constituents less volatile than water at the pressures involved will also condense in the condensation zone, particularly, at least, in the first portion thereof. Hydrocarbons more volatile than water at the pressures involved will progressively go in the latter portion of and beyond the water condensation zone. The most volatile products and fixed gases, these gases including carbon dioxide, will, further, pass into solution in the interstitial hydrocarbons beyond the condensation zone, carbon dioxide also going into solution in interstitial water. The result, then, is a somewhat ill-defined (spatially) zone 24 which has been referred to as part of the unaltered zone, this term being here used for the zone in which the original contents have not been substantially affected, though the hot combustion gases may, in part, have volatilized the more volatile constituents, but may have, merely by temperature rise, driven some dissolved gases out of the liquid phase. The zone 24, as will appear, plays an important part in the operation in accordance with the invention. Beyond this is the zone portion 26 which may only have been affected by either removal of dissolved gases or by solution of gases in view of the high pressures involved.

The procedure in accordance with the invention may now be described. First, forward burning is carried out in conventional fashion. This is initiated in unusual fashion, by locating an electrical heater within the well at the level of the formation to be produced, with injection of air to start combustion in the region immediately surrounding the well. Alternatively, gas or liquid fuel may be burned in the air at the bottom of the well to produce a flame to ignite the immediately surrounding region. After ignition of the formation has been accomplished, the heater may be removed or the initiating fuel discontinued. If the contents of the formation are such as to maintain combustion poorly, there may be for a time injected with the air, gas or other fuel in an amount less than that of a self-combustible percentage so that in the formation proper burning conditions are maintained. This is generally only a transient condition, since temperatures are rapidly produced which will involve permanent maintenance of combustion. Generally, to maintain sufficient rapidity of combustion, the air is introduced at high pressure and the outputs from the producing wells may be throttled to maintain optimum pressure conditions in the formation, though, generally, the pressures are desirably maintained by sufficient air introduction with little or no impeding of flow from the producing wells. The burning then proceeds in conventional fashion.

So long as proper burning rates are maintained, the process may go on normally. The amount of injected air is either measured by a meter or determined from the known compressor characteristics. Pressure in the injection wells is also measured.

Flow from and pressure in the producing wells are also measured and figures of the production are made. These, as is well-known, will give full information concerning the progress of the process, being considered along with the information previously obtained as to the nature of the formation derived from coring, or the previous production history, or in some other conventional fashion.

The beginning of blocking of flow will become evident from the foregoing measurements. In particular, if a given flow of air is maintained, as by the use of a positive compressor, a rise of the pressure differential between the injection wells and the producing wells will indicate the building up of resistance to flow; or, alternatively, if pressures are maintained, and non-positive compressors, such as centrifugal compressors are used, the building up of resistance will be evidenced by reduction of injected air flow. Initial building up of resistance to flow may be tolerated; but when the pressure differential or the decreased air flow rate reaches such a value that, again considering known reservoir conditions, the progress of the conventional procedure is considered unsatisfactory, there will be brought into play, in accordance with the invention, the novel steps of the procedures. These involve, basically, first, the reduction of pressure. This may be accomplished in one, or preferably both, of the condense zones, so as to increase the rate of production.

The rate of injection of air may be substantially reduced without change of throttling at the producing wells. Alternatively, the injection air flow rate may be maintained, but the throttling action at the producing wells may be reduced so as to increase the rate of produced flow. If pumping is used to remove the fluids from the producing wells, the rate of pumping may be substantially increased. Preferably, however, both expedients are used, the rate of air injection being lowered and the rate of withdrawal from the producing wells being increased. The net result of any of these procedures is to produce lowering of the pressures existing in the formation.

The air injection may be stopped entirely for several days; however cessation of air injection for extended periods would be undesirable for several reasons:

First, it is not desirable to have the combustion zone drop below the ignition temperature; it may then become difficult or impossible to restart burning. This may occur if the combustion zone has become fairly remote from the injection wells.

But another reason for maintaining combustion by maintenance of air flow is that it is highly desirable to maintain elevated temperatures particularly in the condensation zone while the pressure is reduced because, as
will immediately appear, the desired results in accordance with the invention arise from the vaporization of water and other volatile constituents from the condensation zone, and the volatilization involves the absorption of heat. Most desirable, therefore, is the maintenance of sufficient air flow to maintain active combustion and production of desired flow, though some reduction of air flow injection is desirable to produce as great a lowering of pressure as possible. The extent to which lowering of injected air rate is effected depends upon the known conditions of the formation and the location of the condensation zone. If, between this zone and the producing well there is such a considerable distance that there is a large pressure drop, the pressure on the condensation zone may be said to be primarily due to the injection rate. In such case the injection rate should be lowered as far as is safe and consistent with the desired maintenance of heat. On the other hand, if the condensation zone is closer to the producing wells so that the major pressure drop due to flow is between the injection wells and the condensation zone, a higher flow rate of injected air may be maintained, the pressure reduction in the condensation zone being then primarily due to increased rates of withdrawal.

The lowering of pressure in the formation, and specifically in the condensation zone, produces volatilization of the injected water and at least the more volatile hydrocarbons therein. As has already been mentioned, the temperature in this condensation zone will, considering water its primary condensate, be approximately that of condensation of water at the high pressure maintained during the conventional burning procedure. Thus, even a moderate reduction of pressure in the condensation zone will result in vaporization of the water therein. This vaporization is accompanied by absorption of heat, and hence cooling takes place which would ultimately stop the vaporization operation. Accordingly it is desirable to lower the pressure as far as possible below the original pressure maintained previously. It will be found that the continuation of combustion has a considerable advantage: coupled with the reduction of pressure, heat is continuously added to the condensation zone to maintain the temperature above the boiling point of the water at the lower pressure, and if the rate of combustion is sufficiently maintained to cause complete vaporization of the water from the condensation zone may be accomplished.

At this point it might appear that the result of the foregoing might be merely that of moving the condensation zone further downstream. While this may occur to some extent, the maintenance of flow of combustion gases will promote previous deposition which will further volatilize the volatile water along with it, as vapor saturation, and since these gases are hot, though progressively cooled in passing through the formation, a quite considerable portion of the water will be carried with them out of the producing wells. But this same situation has another effect which in re-establishing proper flow conditions: even though a water condensation may occur further downstream, the region through which this takes place is so extended that at any point the condensation will result only in relatively small increase in water content in the formation. It is generally a high water content which will produce the blocking action.

But in addition to this, there is another result due to the liberation of dissolved gases downstream of the condensation zone. Under the reduced pressure, large volumes of these gases are produced, giving rise to a driving and sweeping action which will further carry the water vapor along with the more volatile constituents of the hydrocarbons present. Under the reduced pressure, the great volume of these dissolved gases produced would effect a driving action even if the injected air were cut off. The sum total of the situation, then, is the production of a very large amount of gaseous fluid comprising variously at different downstream locations, steam, volatilized hydrocarbons, products of combustion, previously dissolved gases, and vapors of water and more volatile hydrocarbons carried thereby. The result, therefore, is not merely the displacement of the blocking zone to a position further downstream.

Attending the evolution of dissolved gases, the liquid phases in the condensation and following zones shrink in volume so as to contribute to the volume of the gas phase in the porosity of the formation. This further contributes to the reestablishment of free flow conditions. Increase in oil production rate is due to gas expansion from solution, change of phase, and pressure reduction.

What happens progressively during this reduced pressure phase of the operation may be ascertained by analysis of the products passing from the producing wells. The removal of the blocking condition in the condensation zone may be checked by increasing the flow of injected air and measuring the rate of increase of pressure. When it has thus been ascertained that proper flow conditions have been re-established, repressuring may be carried out by increasing the air injection rate and decreasing the production by throttling or by decreasing the pumping rate at the producing wells, as the particular situation determines. If the formation is not too deep, the injection air pressure may be used to drive the products, a mixture of liquids and gases, out of the producing wells; but in the case of deep wells, pumping may be resorted to in the usual fashion.

Following the reestablishment of normal forward burning, this may be continued until blocking in a condensation zone reappears and assumes such a magnitude as to interfere again with the desired rate of progress. The procedure involving the reduction in pressure may then be repeated, and in the complete procedure of burning out the entire formation, this cycle of high and low pressure operations may be repeated as often as may be required.

FIGURE 2 is a diagram which may serve to give a better visualization of what occurs in the carrying out of a procedure as above-described. This is a plot of temperature against distance, the assumption being that the injection region is at the left of this diagram and the production region at or beyond its right, there being arbitrarily assumed conditions existing initially in which the combustion zone is always midway between injection and producing locations. The curve portion at 28 indicates temperature conditions in the burned zone, 30 indicates the maximum temperature conditions characterizing the combustion zone. As already indicated, the zones will never be sharply defined, and generally some combustion will continue in the burned zone through the temperature will be lowered adjacent to the injection wells due to the cooling action of the incoming air. Following the maximum temperature point, there is the cracking zone through which the temperature drops as shown by the portion of the curve at 34. This merges with the plateau 34" of the curve which characterizes the condensation zone. The plateau of temperature here corresponds to the temperature at which condensation, largely of water, takes place at the existing pressure which at this time will be considered to be that involved during normal forward burning. Beyond this condensation region, the temperature again drops due to absorption of heat from the flowing gases, the final temperature reached at 34" being essentially the ambient temperature of the unchanged part of the formation. In the region of this last drop of temperature and beyond, solution of gases takes place.

The portions of the curve so far described correspond to normal forward burning, and may be considered as those existing when it is found desirable, because of blocking, to reduce the pressure as described above.

With reduction of pressure, which, of course, does not occur instantaneously but gradually, as equilibrium conditions are approached in dependence on flow rate, the portions of the curve 34, 34" and 34" shift to 36, 36"
and 36" and then to 38, 38’ and 38". It may be assumed that the curve made up of the last mentioned portions is that corresponding to the termination of the pressure-reduction part of the cycle.

The curve portion 36 represents the advance of higher temperatures and progress of the cracking zone. 36’ is another condensation zone plateau, and the temperature here is that corresponding to the condensation temperature at the partially reduced pressure reached during pressure change. Finally, as pressure equilibrium conditions are established, the cracking zone reaches the location of curve portion 38 and the plateau 38’ represents the condensation zone temperature corresponding to the final pressure achieved. When the region at 38’ is reached, the greater part of the water will have been removed in the form of vapor carried by the flowing gases, which gases will not only by the combustion products but will include the dissolved gases separating out of the liquid phase together with the more volatile hydrocarbons.

It will be noted that the plateau 38’ is more extensive than the plateau 34’. This represents a reduced concentration of the liquid phase in the formation, increasing the effective permeability from the standpoint of gas flow.

The curves 40 and 42 represent the condition existing as repressuring takes place, the curve 42 representing the completion of the repressuring operation and the beginning of normal continuation of the forward burning. The plateau at 42’ represents the temperature of condensation corresponding to the reestablished high pressure. The shift to ambient pressure at 42’ is now displaced in the direction of flow.

The diagram shown in FIGURE 3 is a plot of static pressure against temperature and showing equilibrium conditions in the condensation zone. The curve 43 represents 100% liquid phase and the curve 44, 0% liquid phase, i.e., 100% vapor phase. The intermediate curves indicate variations of percentage liquid content, the critical point being indicated at 46. The point 48 represents the static pressure condition at the time the normal forward burning is interrupted and pressure reduction started.

Point 50 represents the condition which would be attained if theoretically instantaneous pressure drop occurred to the ultimate reduced pressure reached. 52 represents the point corresponding to reduction of temperature at this pressure. Actually, due to flow conditions, the pressure cannot drop instantaneously, but is delayed in time, with temperature drops occurring simultaneously with pressure drops so that the actual changing conditions occur as indicated by the line 54. Repressuring also is somewhat gradual so that it takes place along a line such as 56.

As has already been indicated, the conditions of operation vary widely with the particular formation which is undergoing treatment, depending upon the adoption of optimum rates of burning, as controlled by air injection, and as determined by the best conclusions for desired operation which may be deduced from all circumstances. Accordingly, each particular situation presents its individual problem, and the solution to the problem, from the standpoint of pressures adopted, times permitted for burning, etc., must be left at the discretion of the operator guided by the measurements and analyzes already discussed.

As an example of the foregoing procedure, the burning prior to substantial blocking may be carried out under pressures ranging from about 50 to 2000 lbs, per square inch, with the average pressure gradient between the injection point and production point of the order of 0.1 to 2.0 lbs, per square inch per foot of distance. As fluid builds up, this average pressure gradient may increase to around 3 to 5 lbs, per square inch per foot of distance for a continuous uniform flow of injected air. Localized pressure gradients between the injection and production points may vary over a wide range depending upon the relative position of the point of measurement to the five zones created in the hydrocarbon bearing strata by the thermal process. Pressure gradients may go from as low as 0.1 lb, per square inch per foot in the burned zone to as high as 30.0 lbs, per square inch per foot in the condensation zone. When the average pressure gradient between injection and production points approaches the maximum stated, the liquid pressure gradient becomes prohibitively high for economical production. Accordingly, when such blocking occurs the pressure would typically be reduced in the formation by the amount of 10 to 30%; for example, by cutting down the inflow of air by 25 to 100% of the rate thereby maintained, for an appropriate duration, while maintaining production at substantially the same rate as at an increased rate by pumping. This reduction of pressure in the formation will result in a lowering of the boiling point of water and hydrocarbons to the extent of about 50 to 150°F. to provide the evaporation condition previously described. As a result there would typically arise the following conditions:

(1) An increase in gas saturation would accompany the reduction in temperature and pressure of the condensation zone ranging from 5 to 30% of the pore volume due to vaporization of water and volatile hydrocarbons.

(2) Evolution of gas, both hydrocarbons and products of combustion, from solution in the oil in the ambient zone would occur.

(3) An expansion of free gas existing at the pressure theretofore would occur in proportion to the change in its temperature and pressure in accordance with Boyle’s law.

(4) The expansion of gases and vaporization of liquids would necessitate the removal of products at the producing well at a rate two to five times greater than the theretofore preceding rate. This increase in production rate would result in a more rapid recovery of oil.

(5) An increase in gas permeability due to the increase in gas saturation resulting in an increase in the air injection capacity of as much as twice that of the theretofore injection capacity.

(6) The increase in oil production rate and air injection capacity both working to make the process more profitable and of shorter duration.

While the progress of the method here involved may be followed and controlled by taking into account measurements made as it progresses, as described above, it has been found useful to attempt to simulate on a much reduced scale what is occurring by the operation of a model chosen to conform with the actual conditions being encountered in the field. Operation of such a model with its results extrapolated to field conditions will frequently serve as a useful guide. Such a model may, for example, be provided by a heat-insulated tube of suitable length, the tube then representing a “flow” tube in the actual formation, i.e. a bundle of streamlines having a particular limited cross-section. By measurement of the progress of the process in such a model, and by taking into account the aspects of analogy with the field, a guide is afforded as to what is actually occurring and what should be done, checking, of course, being continuously made against actual measurements in the field operation. Since such a model is highly informative of what actually occurs, it will be instructive to describe operation in a typical model of this sort, as follows:

In such a model a forward burn was initiated in a porous medium containing oil, water and gas at respective saturations of 75%, 15%, and 10% respectively. The forward burn was conducted to approximately 25% of the distance through the combustion tube, and a fluid block developed reducing airflow from an initial 36.5 cubic feet per hour per square foot of cross-sectional area to 4.5 cubic feet per hour per square foot. The rate of advance of the combustion zone was found to de-
crease from 4.1 feet per day to 1.4 feet per day as the fluid block developed and restricted air flow. At the time pressure reduction was then effected, the combustion zone temperature, the condensation zone temperature and the ambient zone temperature were respectively found to be 1000° F., 381° F. and 78° F. The static pressures through the system, when the pressure reduction was initiated, were approximately 250 lbs. per square inch in the burned zone, 200 lbs. per square inch in the condensation zone, and 193 lbs. per square inch in the ambient zone. The reduction in static pressure in the system was accomplished in approximately 45 minutes and this pressure reduction was accompanied by a reduction in temperature of 50° F. and an increase in length of the condensation zone of 100%. Further reduction in static pressure in the condensation zone to the extent of 150 lbs. per square inch and 200 lbs. per square inch resulted in reductions in temperature therein to the extent of 55° F. and 105° F., respectively. During the pressure reduction process the production of oil increased 5.25 fold. When the pressure in the continuation zone reached 50 lbs. per square inch, air injection was again resumed and sustained at a flux of 36.85 standard cubic feet per hour per square foot. The pressures in the burned zone, condensation zone and ambient zone were restored by this flow to 250 lbs. per square inch, 225 lbs. per square inch and 220 lbs. per square inch, respectively. Repetitions of such a cycle will be found to be possible, with restoration of air injectivity following each pressure reduction.

It will be evident from the foregoing that numerous variations in specific procedure may be adopted without departing from the invention as defined in the following claims.

What is claimed is:
1. The method of production of hydrocarbon materials from a hydrocarbon-containing formation penetrated by at least two wells comprising:
   injecting into one of said wells an oxygen-containing gas and supporting thereby combustion of carbonaceous material in said formation with progression of the combustion towards the other of said wells and removal of products from the latter, the foregoing procedure being carried out under elevated pressure conditions in the formation;
   maintaining the foregoing procedure until a substantial resistance to flow through the formation appears between said wells;
   then effecting lowering of the pressure in the formation while maintaining pressure conditions to continue flow of products through the second mentioned well, said lowering of pressure being maintained until said resistance to flow is substantially decreased by reason of vaporization of condensed liquids; and
   thereafter continuing the procedure first above mentioned under elevated pressure conditions in the formation.
2. The method of production of hydrocarbon materials from a hydrocarbon-containing formation penetrated by at least two wells comprising:
   injecting into one of said wells an oxygen-containing gas and supporting thereby combustion of carbonaceous material in said formation with progression of the combustion towards the other of said wells and removal of products from the latter, the foregoing procedure being carried out under elevated pressure conditions in the formation;
   maintaining the foregoing procedure until a substantial resistance to flow through the formation appears between said wells;
   then effecting lowering of the pressure in the formation while continuing the injection of oxygen-containing gas to maintain combustion, and while maintaining pressure conditions to continue flow of products through the second mentioned well, said lowering of pressure being maintained until said resistance to flow is substantially decreased by reason of vaporization of condensed liquid; and
   thereafter continuing the procedure first above mentioned under elevated pressure conditions in the formation.

References Cited by the Examiner

UNITED STATES PATENTS

2,642,943 6/53 Smith --------------------- 166—11
2,771,951 11/56 Simm --------------------- 166—11
2,793,696 5/57 Morse --------------------- 166—11
2,862,557 12/58 Baron van Utenhove et al. 166—11

BENJAMIN HERSH, Primary Examiner.