May 29, 1962 R. L. KOCH ET AL 3,036,632

RECOVERY OF HYDROCARBON MATERIALS FROM EARTH FORMATIONS BY APPLICATION OF HEAT

Filed Dec. 24, 1958 2 Sheets-Sheet 1

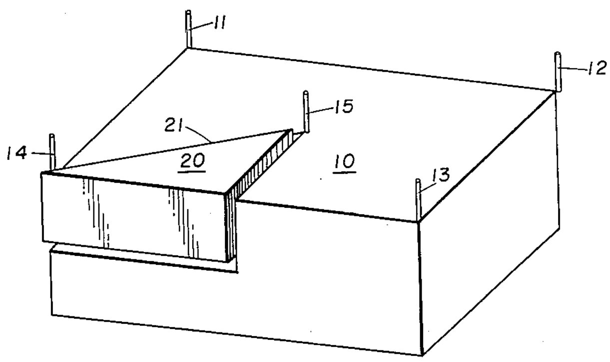

FIG. 1.

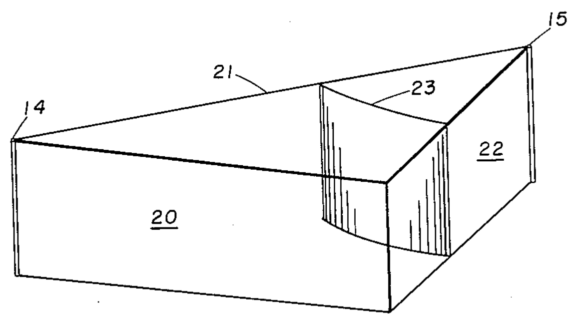

FIG. 2.

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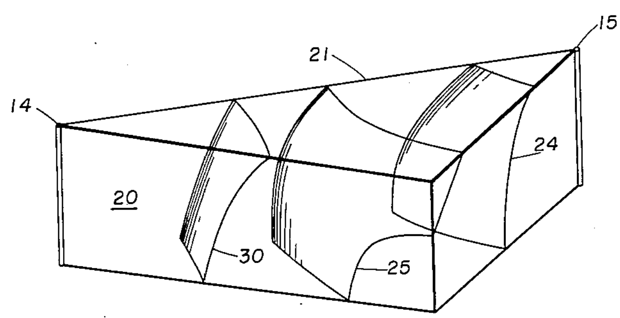

FIG. 3.

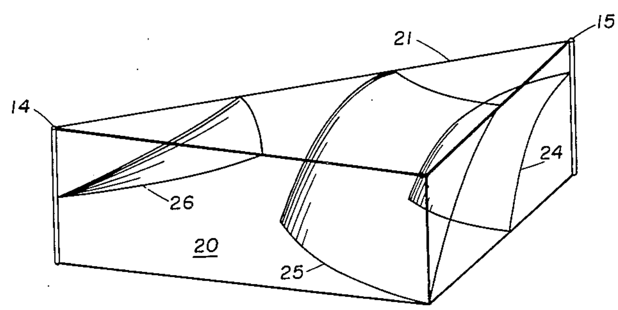

FIG. 4.

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RECOVERY OF HYDROCARBON MATERIALS FROM EARTH FORMATIONS BY APPLICATION OF HEAT

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5 Claims. (Cl. 166—11)

This invention relates to the recovery of hydrocarbon materials from earth formations and relates more particularly to the recovery of hydrocarbon materials from earth formations by the application of heat thereto, said heat being obtained by combustion in place of a portion of the hydrocarbon materials in the earth formation.

Petroleum oil is usually recovered initially from an earth formation containing such hydrocarbon material as a result of gas pressure or natural water drive forcing the oil from the oil-bearing formation through a producing well leading therefrom to the surface of the ground. As recovery of oil from the formation continues, the energy within the formation gradually decreases and finally becomes insufficient to force the oil to the surface of the ground, although a large portion of the original quantity of the oil remains in the formation. To increase the ultimate recovery of the oil, pumping is then employed, but when the rate of recovery by pumping falls to an uneconomically low level, a further increase in the ultimate recovery of the oil may still be economically effected by the employment of such recovery methods as gas drive or water drive. It has recently been proposed to increase the ultimate recovery of the oil by a combustion process.

In the combustion process, an oxidizing gas is passed, as by pumping, through an input well or input wells to the formation and combustion of the oil within the formation is initiated by suitable means. A zone of combustion advances from the input well or input wells to an output well or output wells leading from the formation to the surface of the ground. As the combustion zone advances with continued supply of oxidizing gas to the formation through the input well or wells, combustion gases, oil, and distillation and viscosity breaking products of the oil advance in front of the combustion zone to the output well or wells from which the fluids are removed and thereafter treated for recovery of the desired valuable constituents. The heat of the fluids advancing in front of the combustion zone strips the oil-bearing formation of the greater portion of the oil, leaving behind within the formation a carbonaceous hydrocarbon deposit and the carbonaceous deposit essentially is the fuel consumed in the process.

While the combustion process is effective for the recovery of oil from earth formations, it suffers to some extent from various drawbacks. For example, it is necessary to supply continually oxidizing gas to the input well or wells in order to maintain combustion and the provision of sufficient compressor capacity to supply sufficient oxidizing gas plus the costs of operation of the compressors represent a not inconsiderable item of expense. Further, control of operating variables is required throughout the entire process in order to obtain the maximum yield of oil commensurate with economy of operation which represents another appreciable item of expense.

It is an object of this invention to provide an improved method of recovering hydrocarbon materials from earth formations by the combustion process. It is another object of this invention to recover hydrocarbon materials from earth formations by the application thereto of heat. It is another object of this invention to reduce the cost of

recovering hydrocarbon materials from earth formations where recovery is obtained by application of heat. It is another object of this invention to reduce operational control of process variables in the combustion process for the recovery of hydrocarbon materials from earth formations. Other objects of the invention will become apparent from the following detailed description thereof.

In accordance with the invention, combustion is initiated in an earth formation containing hydrocarbon material, oxidizing gas is passed into the formation through an input well leading thereto whereby the combustion zone is advanced through the earth formation from the input well to an output well leading therefrom, thereafter the supply of oxidizing gas to the earth formation in the direction of the output well is discontinued when the combustion zone has advanced through the formation less than the entire distance from the input well to an output well, the heat in the portion of the formation already traversed by the combustion zone is allowed to transfer therefrom, without any assistance from injection of fluid, into the portion of the formation in the direction of an output well not yet traversed by the combustion zone, and hydrocarbon material is recovered from the output well.

FIGURE 1 is a diagrammatic representation of an earth formation penetrated by an input well and four output wells symmetrically arranged about the input well.

FIGURE 2 is a diagrammatic representation of a portion of the earth formation of FIGURE 1 indicating temperature distribution at the time the supply of oxidizing gas to the formation is discontinued.

FIGURE 3 is a diagrammatic representation of the same portion of the formation as shown in FIGURE 2 indicating temperature distribution at a time after the supply of oxidizing gas is discontinued and heat transfer has occurred without assistance from injection of fluid.

FIGURE 4 is a diagrammatic representation of the same portion of the formation as in FIGURE 1 indicating the temperature distribution at a still later time after the supply of oxidizing gas is discontinued and heat transfer has occurred without assistance from injection of fluid.

We have found that, by procedure of the invention, the hydrocarbon material in the portion of the formation in the direction of the output well not yet traversed by the combustion zone is raised in temperature, without the necessity of injection of fluid, to a point where improved oil recovery is obtained by the resulting lowering of the viscosity of the hydrocarbon material. For example, with a hydocarbon material such as 14° API crude oil, a viscosity change from about 5000 to about 200 centipoises will be effected by increasing the temperature of the oil from about 60° F. to 135° F. A viscosity change of this order of magnitude permits a much easier flow of the oil through the formation with consequent increased ultimate yield of oil.

Hereinabove as well as hereinafter, advance of the combustion zone from the input well to the output well shall mean the maximum distance traversed by the combustion zone along a straight line extending from the output well to the input well.

In carrying out the invention oxidizing gas is passed into the formation through the input well in the direction of the output well until the combustion zone has advanced, by virtue of the formation being supplied with oxidizing gas, a distance equal to at least forty percent of the distance from the input well to the output well from which hydrocarbon material is to be recovered. The oxidizing gas may be passed into the formation in the direction of the output well until the combustion zone has advanced, by virtue of the formation being supplied with oxidizing gas, more than forty percent of the distance from the input well to the output well but ordinarily it is preferred that oxidizing gas be passed into the formation in the direction of the output well no longer than is required to advance the combustion zone ninety percent of the distance from the input well to the output well. In the practice of the invention, the oxidizing gas is passed continuously into the formation in the direction of the output well from the time ignition of the hydrocarbon material in the formation is first effected until the combustion zone has advanced the desired distance. Thereafter, heat is permitted to transfer by conduction without any assistance from injection of fluid in the direction of the output well from the portion of the formation traversed by the combustion zone to the portion of the formation not yet traversed by the combustion zone. However, if desired, the oxidizing gas may be passed intermittently into the formation in the direction of the output well until the total of the increments of the distances advanced by the combustion zone while oxidizing gas is being passed into the formation is equal to the desired distance between the input well and the output well.

In the combustion process, the combustion zone advances from the input well to the output well during the time that oxidizing gas is being passed to the formation in the direction of the output well. By conduction during the time that gas is not being passed to the formation in the direction of the output well, the portion of the formation lying in front of the combustion zone may be heated above the ignition temperature of the hydrocarbon material contained therein. However, this is not to be regarded as advance of the combustion zone, and, where intermittent operation is employed, the total time that oxidizing gas is passed into the formation in the direction of the output well is such that the accumulated distance of advance of the combustion zone with each passage of oxidizing gas in the direction of the output well is equal to the desired distance.

An essential step of the invention is discontinuance of the supply of oxidizing gas to the earth formation in the direction of the output well and allowance of transfer of the heat without any assistance from injection of fluid from the portion of the formation already traversed by the combustion zone to the portion of the formation in the direction of an output well not yet traversed by the combustion zone. This step involves not only shutting off the supply of oxidizing gas but stopping flow of any liquid or gaseous medium into the input well through the formation in the direction of the output well. As a result of this step, the hydrocarbon material in the portion of the formation in the direction of the output well not yet traversed by the combustion zone is increased in temperature with resulting ease of flow and recovery, as hereinabove mentioned. But, this increase in temperature is obtained without the necessity of any expenditure of energy as would be involved in maintaining combustion during this time by passing oxidizing gas to the formation in the direction of the output well or by transferring heat during this time from the portion of the formation traversed by the combustion zone to the portion of the formation in the direction of the output well not yet traversed by the combustion zone by passing an inert fluid through the formation in the direction of the output well. Further, no control of process variables is required while heat is being transferred without assistance from injection of fluid.

Transfer of heat from the portion of the formation already traversed by the combustion zone to the portion of the formation in the direction of the output well not yet traversed by the combustion zone without any assistance from injection of fluid may cause production of hydrocarbon material from the output well depending upon the properties of the hydrocarbon material within the formation, the temperatures attained within the formation, and the proximity of the combustion zone to the output well. However, production of hydrocarbon material from the output well may not occur as a result of this transfer of heat. It is, therefore, necessary, following the transfer of heat, to pass a fluid from the input well through the formation to the output well to drive the hydrocarbon material to the output well in order to obtain production therefrom.

In the practice of the invention, transfer of heat without any assistance from injection of fluid from the formation already traversed by the combustion zone to the formation in the direction of the output well not yet traversed by the combustion zone is permitted to occur for a period of time. This period of time may vary but must be appreciable in order that the benefits of permitting heat to transfer without any assistance from injection of fluid are obtained. Accordingly, this period must be at least as great as one month, or thirty days. In a preferred embodiment of the invention, this period, which is at least as great as one month, is also sufficiently great that heat will have transferred through the formation without assistance from injection of fluid to the extent that the temperature of the formation at the output well will have risen measurably above its temperature existing at the time the supply of oxidizing gas, and combustion, was discontinued. By a measurable rise of temperature is meant an increase in temperature which is detectable by instruments ordinarily employed in the art of recovering hydrocarbon materials from earth formations by the application of heat. These instruments include thermometers or thermocouples. A preferred rise in temperature is about 50° F.

Following the step of transfer of heat without any assistance from injection of fluid from the formation already traversed by the combustion zone to the formation in the direction of the output well not yet traversed by the combustion zone, a fluid is injected into the input well through the formation to the output well to drive hydrocarbon material within the formation to the output well. By the term "fluid," gases as well as liquids are included. This step of injecting fluid into the input well through the formation to the output well, in order that the benefits of the invention with respect to control of process variables are obtained, must be carried out under conditions that combustion will not occur. Thus, this step may be carried out employing a fluid which will not support combustion. Such fluids include carbon dioxide, water, hydrocarbons such as methane, etc.

This step of injecting fluid into the output well through the input well through the formation to the output well may also be carried out employing a fluid, such as air, which will support combustion. However, where a fluid which will support combustion is employed, in order that this step be carried out under conditions that combustion will not occur, the maximum temperature within the formation in the path of the flow of fluid, and the temperature of the fluid upon entrance into the formation, must be below the ignition temperature of the hydrocarbon deposit. Accordingly, where, following the step of transfer of heat without any assistance from injection of fluid, a fluid which will support combustion is employed to drive hydrocarbon material within the formation to the output well, the period of time during which transfer of heat without any assistance from injection of fluid is permitted to occur must be sufficiently great that the maximum temperature between the input well and the output well in the path of the flow of fluid is below the ignition temperature of the hydrocarbon deposit within the formation. Ignition temperatures of the hydrocarbon deposit within the formation may vary depending upon the character of the deposit. However, ordinarily, the ignition temperature of the hydrocarbon deposit will be at least as great as 400° F. Thus, where a fluid which will support combustion is to be employed to drive hydrocarbon material within the formation to the output well, the period of time that heat is permitted to transfer without assistance from injection of fluid must not only be at least as great as one month but also must be sufficiently great that the maximum temperature within the formation is not in excess of 400° F.

A formation being treated by the subsurface combustion process may have one input well leading thereto and one output well leading therefrom. In most instances, however, the formation will have a plurality of output wells leading therefrom and the output wells are ordinarily arranged in a symmetrical pattern around the input well. In carrying out the process of the invention where the earth formation has only one output well leading therefrom, the supply of oxidizing gas to the formation is discontinued when the combustion zone has advanced the desired distance between the input well and the output well. On the other hand, in carrying out the process of the invention where the earth formation has a plurality of output wells leading therefrom, the supply of oxidizing gas is discontinued by imposing a back pressure successively upon each of the output wells when the combustion zone has advanced the desired distance from the input well to each individual output well whereby the advance of the combustion zone to that output well is halted. The imposition of the back pressure is most conveniently effected by closing off each well although other methods may be employed if desired. When back pressure has been imposed upon the last of the output wells leading from the formation, the supply of oxidizing gas is discontinued. In the event the combustion zone advances at a uniform rate between the input well and each of the output wells, the supply of oxidizing gas is discontinued when the combustion zone has traversed the desired distance.

The following will be illustrative of the invention.

Referring to FIGURE 1, a portion of an earth formation delineated by four output wells leading therefrom is indicated generally by the numeral **10**. Output wells **11**, **12**, **13**, and **14** lead from the formation and are arranged in a symmetrical pattern, namely, a square, about input well **15** leading to the formation. The temperature of this formation is 100° F. Combustion is initiated in the formation at the input well **15** and oxidizing gas is passed into the well whereby the combustion zone advances from the input well to each of the output wells. For purposes of the example, only that portion **20** of the formation will be considered with respect to the temperature distribution therein. However, it will be understood that similar temperature distribution will occur within similar segments of the formation **10**.

Oxidizing gas is passed into the formation until the combustion zone has advanced forty percent of the distance along the line **21** between the input well **15** and the output well **14**, at which time the supply of combustion gas is discontinued. By means of thermocouples, the temperature over that portion of the segment **20** represented by the volume **22** bounded by the surface **23** in FIGURE 2 was determined to be 1100° F. on the average.

With the supply of combustion gas discontinued and heat permitted to transfer from the portion of the formation behind the combustion zone to the portion of the formation not yet traversed by the combustion zone without any assistance from injection of fluid, the heat distribution at a period of time one year following discontinuance of the supply of combustion gas is as indicated in FIGURE 3. At the surface **24** the temperature is 250° F., at the surface **25** the temperature is 200° F., and at locations between surfaces **24** and **25** the temperature varies between 200° and 250° F. depending upon the distance between the surfaces. At the surface **30** the temperature is 175° F., and at locations between the surfaces **30** and **25**, the temperature varies between 175° and 200° F. depending upon the distance between the surfaces.

Two years after the supply of oxidizing gas to the formation has been discontinued and transfer of heat is permitted to take place without assistance from injection of fluid, the temperature distribution within the formation is as indicated in FIGURE 4. Over surface **24**, the temperature is 250° F., over surface **25** the temperature is 200° F., and over surface **26** the temperature is 175° F., and it will be noted that the 175° F. surface has advanced a considerable distance toward the output well and the lower portion thereof has extended halfway to the top of the output well. As a result of the increase in temperature of the greater portion of the formation from its original temperature of 100° F., the hydrocarbon material within the formation is considerably reduced in viscosity with resultant improvement in ease of production. Injection of fluid at this time into the input well **15** assists in driving the hydrocarbon material within the formation to the output well **14**.

The invention may be employed in connection with the combustion process for the recovery of petroleum oil from partially depleted subterranean petroleum oil reservoirs where the reservoir energy has decreased to the point that oil is no longer forced to the surface and particularly to the point that the rate of recovery by pumping is so low as to be uneconomical. The invention may also be employed in connection with the combustion process for the recovery of petroleum oil from a subterranean reservoir wherein the oil has such high viscosity that efficient recovery by water drive or other conventional means cannot be effected. Further, the invention is applicable in connection with the combustion process for the recovery of hydrocarbon materials from earth formations such as tar sands, for example, those existing in the Athabasca region of Canada and elsewhere.

This application is a continuation-in-part of our copending application Serial No. 371,291, filed July 30, 1953.

Having thus described our invention, it will be understood that such description has been given by way of illustration and example and not by way of limitation, reference for the latter purpose being had to the appended claims.

What is claimed is:

1. In a process for the recovery of hydrocarbon materials from an earth formation wherein an oxidizing gas is passed to said formation through an input well leading thereto and forced through said formation to at least one output well leading therefrom, combustion of a portion of the hydrocarbon materials is maintained within said formation, and a combustion zone is advanced through said formation as a result of the passage of said oxidizing gas, the improvement comprising passing said oxidizing gas to said formation through said input well in the direction of said output well until said combustion zone as a result of the passage of said oxidizing gas to said formation has advanced more than 40 percent but less than 90 percent of the distance on a straight line between said input well and said output well, discontinuing passage of gas through said input well to said formation for a period of time which is appreciable and is at least as great as one month thereby permitting heat without assistance from injection of fluid in the direction of said output well during said period of time to transfer from the portion of said formation traversed by said combustion zone to the portion of said formation in the direction of said output well not traversed by said combustion zone, and thereafter, to assist in production of hydrocarbon materials from said output well, passing fluid through said formation to said output well under conditions that combustion of said hydrocarbon materials in said formation is absent.

2. In a process for the recovery of hydrocarbon materials from an earth formation wherein an oxidizing gas is passed to said formation through an input well leading thereto and forced through said formation to at least one output well leading therefrom, combustion of a portion of the hydrocarbon materials is maintained with-

in said formation, and a combustion zone is advanced through said formation as a result of the passage of said oxidizing gas, the improvement comprising passing said oxidizing gas to said formation through said input well in the direction of said output well until said combustion zone as a result of the passage of said oxidizing gas to said formation has advanced more than 40 percent but less than 90 percent of the distance on a straight line between said input well and said output well, discontinuing passage of gas through said input well to said formation for a period of time which is appreciable and is at least as great as one month thereby permitting heat without assistance from injection of fluid in the direction of said output well during said period of time to transfer from the portion of said formation traversed by said combustion zone to the portion of said formation in the direction of said output well not traversed by said combustion zone until the temperature of said formation at said output well has risen measurably above its temperature existing at the time said passage of gas to said input well was discontinued, and thereafter, to assist in production of hydrocarbon materials from said output well, passing fluid through said formation to said output well under conditions that combustion of said hydrocarbon materials in said formation is absent.

3. In a process for the recovery of hydrocarbon materials from an earth formation wherein an oxidizing gas is passed to said formation through an input well leading thereto and forced through said formation to at least one output well leading therefrom, combustion of a portion of the hydrocarbon materials is maintained within said formation, and a combustion zone is advanced through said formation as a result of the passage of said oxidizing gas, the improvement comprising passing said oxidizing gas to said formation through said input well in the direction of said output well until said combustion zone as a result of the passage of said oxidizing gas to said formation has advanced more than 40 percent but less than 90 percent of the distance on a straight line between said input well and said output well, discontinuing passage of gas through said input well to said formation for a period of time which is appreciable and is at least as great as one month thereby permitting heat without assistance from injection of fluid in the direction of said output well during said period of time to transfer from the portion of said formation traversed by said combustion zone to the portion of said formation in the direction of said output well, and thereafter, to assist in production of hydrocarbon materials from said output well, passing a fluid which will not support combustion of said hydrocarbon materials in said formation through said formation to said output well.

4. In a process for the recovery of hydrocarbon materials from an earth formation wherein an oxidizing gas is passed to said formation through an input well leading thereto and forced through said formation to at least one output well leading therefrom, combustion of a portion of the hydrocarbon materials is maintained within said formation, and a combustion zone is advanced through said formation as a result of the passage of said oxidizing gas, the improvement comprising passing said

oxidizing gas to said formation through said input well in the direction of said output well until said combustion zone as a result of the passage of said oxidizing gas to said formation has advanced more than 40 percent but less than 90 percent of the distance on a straight line between said input well and said output well, discontinuing passage of oxidizing gas through said input well to said formation for a period of time which is appreciable and is at least as great as one month thereby permitting heat without assistance from injection of fluid in the direction of said output well during said period of time to transfer from the portion of said formation traversed by said combustion zone to the portion of said formation in the direction of said output well until the maximum temperature in the formation between the input well and the output well in the path of the flow of fluid through said formation is below the ignition temperature of said hydrocarbon materials in said formation, and thereafter, to assist in production of hydrocarbon materials from said formation, passing fluid through said formation to said output well at a temperature below the ignition temperature of said hydrocarbon materials in said formation.

5. In a process for the recovery of hydrocarbon materials from an earth formation wherein an oxidizing gas is passed to said formation through an input well leading thereto and forced through said formation to at least one output well leading therefrom, combustion of a portion of the hydrocarbon materials is maintained within said formation, and a combustion zone is advanced through said formation as a result of the passage of said oxidizing gas, the improvement comprising passing said oxidizing gas to said formation through said input well in the direction of said output well until said combustion zone as a result of the passage of said oxidizing gas to said formation has advanced more than 40 percent but less than 90 percent of the distance on a straight line between said input well and said output well, discontinuing passage of gas through said input well to said formation for a period of time which is appreciable and is at least as great as one month thereby permitting heat without assistance from injection of fluid in the direction of said output well during said period of time to transfer from the portion of said formation traversed by said combustion zone to the portion of said formation in the direction of said output well not traversed by said combustion zone until the temperature of said formation at said output well has risen at least 50° F. above its temperature existing at the time said passage of gas to said input well was discontinued, and thereafter, to assist in production of hydrocarbon materials from said output well, passing fluid through said formation to said output well under conditions that combustion of said hydrocarbon materials in said formation is absent.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,036,632 May 29, 1962

Robert L. Koch et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 5, line 41, before "well" insert -- input --.

Signed and sealed this 16th day of October 1962.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents