FIG. 1

FIG. 2
METHOD FOR IN-SITU UTILIZATION OF FUELS BY COMBUSTION

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Application March 3, 1954, Serial No. 413,904

5 Claims. (Cl. 262—3)

This invention relates to methods for in situ utilization of carbonaceous deposits capable of combustion with combustion supporting gases to produce heat utilizable economically for heat treatments both above and below ground, particularly from fuels or other deposits which cannot be mined and utilized above earth in an economically way.

There are many such deposits that can not be economically mined. Some cannot be so exploited because the deposits have too low a content of combustible matter to be used in that way economically. Others which may contain a satisfactory content of combustible matter, are so situated in the earth, as in depth or thickness of layer, as to make the mining operation unattractive.

Methods of underground combustion have been heretofore proposed but have not been successful because of the difficulty of distributing the combustion supporting gas such as air, in the rock in such manner as to obtain a substantially uniform combustion zone. The introduction of the combustion supporting gas through a borehole into the rock, does not result in uniform flow of the gas because such flow is usually disturbed by the presence of cracks, laminations, cavities, etc. in the rock. As a result of such non-uniform flow, the combustion zone may advance along cracks in one direction very rapidly, to a relatively distant location from the inlet hole, while in the meantime, the advance in another direction may be very slow due to a greater tightness or impermeability or density of the structure. Under such circumstances, it has been impossible by prior art procedures to control the heat distribution to the parts of the rock where the heat treatment is to be applied.

Among the objects of the present invention are included methods for combustion in situ of combustible organic material in subterranean deposits with substantially uniform heat distribution therein despite irregularities in the formation that might otherwise interfere with uniformity of heat distribution.

Other objects include the production of a controlled combustion zone and a controlled heat transfer to other portions of the rock or formation or deposit.

Further objects and advantages of this invention will appear from the more detailed description set forth below, it being understood that such more detailed description is given by way of illustration and explanation only, and not by way of limitation since various changes thereafter may be made by those skilled in the art without departing from the scope and spirit of the present invention.

In connection with that more detailed description, the drawings show the following:

Figure 1 is a plan view of a field showing a number of boreholes for utilization in connection with the present invention;

Figure 2 is a transverse vertical section through the field of Figure 1;

Figure 3 is an enlarged fragmentary view of a portion of the section of Figure 2;

Figure 4 is a section on the line 4—4 of Figure 3; and

Figure 5 is a section on line 4—4 of Figure 3 illustrating the heat front developed by the present invention.

The present invention produces combustion in situ of combustible organic material contained in subterranean deposits under controlled conditions to produce a controlled combustion zone and a controlled heat transfer from the combustion zone of other parts of the rock, formation, or deposit. The controlled conditions are obtained by withdrawal of combustion gases from boreholes in the vicinity of the air-inlet boreholes. This withdrawal may be attained for example by suction in the pipelines, connected to the outlet holes. Thereby the hot combustion gases are forced to flow in certain directions and their flow can thus be regulated and controlled. When passing through the outlet holes towards the exit thereof, they give off at least part of their heat content to the walls of the borehole, thus raising the temperature of said walls to a temperature that is substantially uniform or even heat transfer takes place from said walls to the surrounding parts of the rock.

The invention is applicable to any subterranean deposits of combustible organic material including oil, shale, and oil shale coke (the latter being formed by in-situ pyrolysis of oil shale), tar sand and sand coke (the latter being formed by in-situ pyrolysis of tar sand), oil sand and depleted oil sand, (still retaining a small amount of oil), lignite, coal, or other carbonaceous and combustible or fuel type materials.

For these purposes, any combustion supporting gas such as air or other oxygen containing gas, is introduced to the deposit to produce a combustion zone and to form hot combustion products, the latter being passed through the deposit or portion thereof where they are withdrawn, usually in the vicinity of the inlet boreholes for the combustion supporting gases, the heat from said combustion products serving to heat the walls of the outlets and thereby adjacent organic material to form valuable products containing gases and vapors or both.

The latter are recovered separately from and substantially free of the combustion products, at a point or points spaced from the point or points where the combustion products are withdrawn.

Accordingly, methods of combustion in situ may be utilized wherein deposits pierced by boreholes in successive alignment serve for introduction respectively of combustion supporting gas, removal of combustion products, and separate removal of valuable products including gases or vapors or both from combustion products. When the flow of valuable products has ceased or has been reduced to a low value, the borehole which initially served for introduction of the combustion supporting gas is sealed off, the latter gas is then introduced into a borehole theretofore for collection of combustion products, the combustion products are collected in the borehole theretofore used for reception of the valuable products, and an additional successive aligned borehole is then utilized for recovery of the valuable products, the relation of heating and heat transfer described above being maintained in the new arrangement. In this way, the combustion zone may be advanced as desired in the deposit or formation. And by repeating the advance in this way, it is possible to carry out the combustion of the entire or any part of the deposit under controlled conditions advancing through the deposit.

Further features of the invention will appear from the following description thereof in connection with the figures of the drawings, without however any limitation thereto.

Figure 1 is a horizontal drawing of a field, showing a number of boreholes for the successive use as outlets. A for volatilized products, obtained by heat treatment.
of the fuel containing rock layers, outlets B for combustion gases, and injection holes C for air or other combustion-supporting gases. The process may be a continuous one and as the treatment of the field proceeds, new holes A for drilling-holes are drilled, the former holes for volatile products are changed to act as outlets for combustion gases and the former combustion gas outlets are changed to act as air inlet holes. Behind the rows of air inlet holes are shown some rows of holes D, having been used for the mentioned purposes, but no longer in use and being sealed or closed.

Fig. 2 is a vertical section through the layers of overburden E, and the layers containing fuel F. The section also shows the location of the above mentioned rows of holes.

Fig. 3 is an enlarged part of Fig. 2, showing one air inlet hole C supplied with air and one combustion-gas outlet hole B which is exhausted. The figure shows how the combustion zone advances mainly in the fissures and cavities of the rock. The dotted line G shows the location of the combustion zone at a given moment. It is evident that the heat transfer to the surroundings will be very irregular from a hot surface of such an irregular shape. The combustion products not being forced to flow, they will spread in the rock in the air inlet tube, especially along cracks 1, 2, etc. and fissures in the layers. This irregular flow is shown in Fig. 4, which is a horizontal section through part of the fuel deposit, on the line 4—4 in Fig. 3. The line H illustrates the location in this section of the combustion zone at a given moment. The irregularity of advance of the heating zone is thus apparent.

If, however, the flow of combustion gases is directed by applying a lower pressure in the row of outlet holes B than the pressure in the surrounding rock, the combustion zone will be more regularly shaped as shown in Fig. 5, which is a horizontal section, corresponding to Fig. 4. Even if there may remain some irregularities in the combustion zone, it is evident that the regular heat flow in this case is much improved compared to that in the case, illustrated in Fig. 4. The essential improvement in the regular heat flow is, however, created through the regular shape of a hot, cylindrical surface around each outlet hole B. The hot combustion gases, collected in each hole, give off part of their heat to the walls of these holes B. If the same subpressure is maintained in the holes B, as in the product gas outlets A, there is no flow of fluids in direction from A to B or vice versa. Thus those parts of the walls of the B-holes, which face the row of A-holes, are undisturbed by flows in any cracks or other cavities. The heat, which is supplied by the hot combustion gases, arriving from the opposite side of the holes, and ascending vertically through the B-holes, is thus fairly equally distributed along the hole wall. Thus a hot body is created around the hole, and the part of this hot body, which faces the row of A-holes, is almost cylindrical. The heat transfer by conduction in the rock towards the zone, where the heat is to be utilized (the pyrolysis zone, cracking zone, etc.), will thus be regular and the shape of the heat wave, moving forwards through the fuel deposit, will be that of a surface consisting of a number of vertical semicylindrical surfaces. The heat transfer conditions may be substantially the same as in methods, where heat is supplied through electrically heated or gas-fired heating tubes, inserted in drillholes.

In order not to get combustion gases and product vapors mixed, the same pressure should be maintained in the hole rows B and A. Therefore it is possible to collect the product vapors through the A-holes and the combustion vapors through the B-holes.

The equipment for carrying out the above-mentioned combustion method includes the boreholes, which may be arranged in any regular hole-pattern, covering the actual field, for instance a triangular, square or hexagonal pattern, and tubes which may be inserted in the boreholes. The tubes may be perforated in conventional manner along the part of the tube which passes through the fuel-containing layers, the purpose of the perforations being to provide a distribution of injected fluid through the whole fuel-containing layer, or they may be open in their lower ends and ending at a certain level, for instance at the top of the fuel deposit. The open tubes may be used in deposits that are consolidated and the whole layer being of approximately the same permeability to fluids, for instance oil shale and oil shale coke.

The tubes in the bore-holes pass through the overburden and around each tube a packer may be arranged in the overburden in order to prevent fluids from escaping from or leaching to the fuel deposits between the tube and the borehole.

Above ground the tubes are valved and connected to either air compressors (when the holes are used for air injection) or fans or blowers (when the holes are used as gas or vapor outlets). The valves may be manually or automatically operated, to maintain pressures wanted in the tubes. The vapor outlets in tubes A should further be connected with means for condensation and collection of the obtained air vapors and other products.

Example

In a run with combustion of oil-shale coke, left behind after oil had been recovered by the electrothermal method (Ljungstrom, U. S. Patent No. 2,634,961), carried out by the Swedish Shale Oil Company, at Kvantorp, Sweden, the hole pattern was a hexagonal one, the edge length of the hexagon unit being 2.20 meter. The thickness of the overburden was about 8 meter and the thickness of the shale coke was about 15 meters. The diameter of the boreholes was about 0.60 meter, and their depth was 32 meters thus passing to the bottom of the shale coke. The inserted tubes had a diameter of about 0.055 meter, the annular space between the borehole and the tube being packed with fine-grained sand. The length of the tubes was about 9 meters and the lower ends of the tubes was located about 0.5 meter below the top of the shale coke layer. Below the tube ends the boreholes were open through the shale coke.

When the stated run was performed, air was blown into three adjacent holes in an amount of between 100 and 300 m3/hour, totally. The pressure required to force the air into the rock was about 150 mm. Hg (gauge). During the air insertion temperature measurements were made and gas products were taken off at several points, distributed at different distances from the injection hole group. The shale coke had from the beginning a temperature of about 300° C, which was sufficient for igniting the coke, when air was injected. (The heat of the coke originated from the earlier electrothermal heating of this field.) The movement of the combustion gases in the layers could be followed by means of gas products, taken from different points in the field. Before the run was started, the whole shale oil layer was filled with gaseous or vaporized hydrocarbons at a pressure of about 100 mm. Hg (gauge) remaining from the electrothermal pyrolysis of the shale. This pressure was rather equally distributed in the whole shale coke body. It was found that the combustion products spread in all directions from the injection hole group. The velocity of advancement was about the same in all directions except in one, in which the combustion gases flowed much more rapidly. At a certain moment of the run, the radius, within which combustion products were obtained was about 10-12 meter. In a certain narrow direction, however, it was found that the combustion gases had moved not less than 27 meters from the inlet hole group. The faster flow in this direction must have been due to a crack or other irregularity in the rock in this direction.

In order to show that the flow of the combustion prod-
products could be controlled from the surface, the run was repeated with some of the outlet hole valves open to the atmosphere. At these points the pressure in the rock was thus lowered below the pressure of the surroundings (about 100 mm. Hg (gauge)), the run conditions thus being of the same effect as if a suction fan had been connected to outlet points in rock layers, where the original pressure was atmospheric pressure.

In the repeated run it was found that the combustion gases only advanced in the directions towards the open holes. No essential flow in other directions was found to take place, not even in the direction of the crack in the rock.

It was thus found possible to direct the flow of combustion products in desired directions in the rock by means of pressure control on the holes.

In the description of the invention, given above, its usefulness for in-situ-pyrolysis or other heat treatment of shale has been illustrated. The same process of directing the advancement of the combustion zone and of withdrawal of hot combustion gases may also be used as a means of recovery from underground sources of heat for other purposes, for instance for heating of buildings or other structures above ground. The heat of the combustion gases may also be utilized for heat treatment of other underground deposits in the vicinity whereby the hot combustion gases are piped in for example insulated pipes to the actual deposits. Thus the heat value of a shale-coke-containing field may be used for preheating an oil-shale field in another location, or for other purposes.

Having thus set forth my invention, I claim:

1. A method for combustion in situ of combustible organic material in subterranean deposits pierced by inlet and outlet boreholes which comprises introducing a combustion supporting gas through an inlet borehole to said combustible material to produce a combustion zone and to form hot combustion products, passing the products of combustion through the deposit to heat adjacent organic material to form valuable products including gases and vapors, collecting and removing said valuable products including gases and vapors separately from said products of combustion at a first outlet borehole which is located a distance from said combustion zone, collecting and removing the products of combustion separately from the valuable products at a second outlet borehole, said second outlet borehole being located between said first inlet borehole and said first outlet borehole, the pressures at both of said first and second outlet boreholes being below atmospheric and substantially equal; and being lower than pressures at said inlet borehole.

2. A method as set forth in claim 1, which comprises removing said products of combustion from said second outlet borehole while retaining sensible heat to a point above the ground and passing them while retaining substantial sensible heat to a zone adjacent the combustion zone as a source of heat for said combustion zone.

3. A method as set forth in claim 1, wherein a plurality of inlet and outlet boreholes are provided to form a pattern of boreholes, maintaining a pressure differential along a direction between inlet boreholes at which combustion supporting gas is introduced and second outlet boreholes at which combustion gas is withdrawn thereby causing predirected advancement of the combustion zone along said direction.

4. A method as set forth in claim 3, including the step of flowing combustion gases substantially in one direction towards second outlet boreholes thereby maintaining a substantially uniform heat distribution in said deposit between the inlet borehole for introduction of combustion supporting gas and the first outlet borehole for removal of said valuable products of combustion, said uniform heat distribution being undisturbed by combustion taking place in cracks, fissures and cavities.

5. The method as set forth in claim 3, comprising successively adding an aligned outlet borehole which is in advance of and in alignment with said advancing combustion zone for the removal of valuable products free of combustion products while sealing off said inlet borehole theretofore used for introduction of combustion supporting gas, introducing the combustion supporting gas to said second outlet borehole theretofore used for removal of combustion products and removing combustion products from the first outlet borehole theretofore used for the removal of valuable products, thus advancing the combustion zone for treatment of the deposit.

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