Fig. 1

Fig. 2

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June 16, 1959
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APPARATUS FOR RECOVERING COMBUSTIBLE SUBSTANCES
FROM SUBTERRANEAN DEPOSITS IN SITU
Filed Jan. 4, 1954

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2,890,755
Fig. 3

Fig. 4

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APPROATUS FOR RECOVERING COMBUSTIBLE SUBSTANCES FROM SUBTERRANEAN DEPOSITS IN SITU

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Application January 4, 1954, Serial No. 401,972

3 Claims. (Cl. 166—59)

This invention relates to a heating device for heating deposits in the ground in situ, i.e., in their natural location.

In the treatment of geological deposits in the ground for recovery of valuable products in a liquid and/or gaseous state it has sometimes proved possible to avoid mining by heating the deposit in situ. Said heating method can be employed when exploiting, for example, shale formations, tar sand deposits or sulphur deposits.

Heating of geological deposits in their natural location has been practiced in prior art on a large scale, at least as far as oil shale deposits are concerned, by means of heating elements or members introduced down into the deposit as is disclosed in the French patent specification No. 1,013,679 which is referred to for a more detailed description of the method. As in the treatment of fuel-carrying deposits considerable quantities of combustible gas are recovered normally, it is easy to understand that effort should be made for developing a heating method in which said gas can be used directly as fuel. In this method the losses and additional expenses caused by the indirect way over a steam power plant, can be avoided or at least considerably reduced.

The deposits to be treated in situ should preferably be covered by an overburden of, for example, limestone. Such overburden reduces the risk of valuable products formed by the heating operation escaping due to leakage. If such covering overburden does not exist, the deposit intended to be exploited is not allowed to be heated in the portion thereof adjacent the surface of the ground. But even if a cover of overburden exists, it is often not desirable that heat be supplied to said cover. With respect to the underlying deposit the rule is that a uniform yield of heat to the entire deposit is desirable, but sometimes it is more advantageous initially to heat a minor zone of the deposit only and subsequently to displace said heating zone successively.

The most practicable method of heating in situ appears to consist in introducing tubular heating members vertically downwards from the surface of the ground into the deposit. If the heat is supplied in the form of electrical energy it does not involve any specific difficulties to attain the desired distribution of the heat yielded, since it is quite sufficient to dispose resistance coils at those portions of the heating device which are to be heated. There are, however, considerable difficulties to be met if the heat is desired to be generated by combustion. Introduction of a convenient gas burner downwards into the tubular heating device results in a very unequal distribution of heat, a marked zone of the heating curve appearing around the flame proper. Said drawback can at least to a considerable extent be overcome by providing, in a plurality of flames on various levels in the long tubular heating device. This expedient is, however, associated with several inconveniences caused by the obvious difficulties in obtaining the most suitable proportion between the quantities of fuel and oxygen supplied to each individual flame.

One principal object of the present invention is to provide a heating device permitting supply of an intermixture of fuel and oxygen from the surface of the ground to the places within the device where the combustion is desired to be started and maintained.

A further object of the invention is to provide a heating device of considerably simplified construction compared with the prior heating devices mentioned above.

A still further object of the invention is to provide a heating device which is both economical in manufacture and reliable in operation.

A still further object of the invention is to provide a heating device permitting in a simple manner the creation of a limited heating zone displaceable along the device.

Further objects and advantages of the invention will be apparent from the following description considered in connection with the accompanying drawings, which form part of this specification, and of which:

Figs. 1 to 4 are longitudinal sectional views of heating devices constructed according to four embodiments of the invention, and of surrounding geological formations into which the heating devices have been introduced.

The drawings present the heating devices on different scales with respect to their longitudinal and lateral dimensions. In reality the devices have a length of 20 to 100 metres, for example, whereas their exterior diameter normally does not surpass 1 decimetre.

As will be seen from the drawings, the heating device comprises a tubular casing 10 and an inner tube substantially concentric with said casing. The casing 10 is introduced into a vertical hole or channel bored or otherwise formed in a downward direction from the surface of the ground. Said hole or channel penetrates for a little distance into a geological stratum 11 located below the fuel-carrying deposit 12 to be exploited. The heating of the boundary layer of the stratum 11 adjacent the deposit 12 is adapted to counteract collection due to gravity of valuable products generated by the heating process. Said heating also prevents heat from being transferred from the deposit 12 to the underlying stratum 11 whereby uniform heating of the lower part also of said deposit is assured.

According to the embodiments presented in the drawings, the deposit 12 is assumed to be covered by a stratum 13 of limestone, above which is a layer 14 of earth the upper surface of which forms the surface of the ground. The interspace between the wall of the hole or channel and the casing 10 is filled with a granular material 15 such as sand, for example, in a manner disclosed in the aforesaid French patent.

Above the surface of the ground the casing 10 is provided with a discharge tube 16 and a sealing cover 17 on which a stuffing box 18 is placed. By means of said stuffing box 18 the casing 10 is connected with the inner tube the lower end of which is on a level higher than the bottom of the casing 16.

Referring to the embodiment shown in Fig. 1, the inner tube consists of two parts, a wider lower part 19 and a narrower upper part 20. Said two parts are interconnected by a conical part 21 disposed on a level coinciding with the upper boundary surface of the deposit 12.

A mixture of fuel and oxygen is introduced into the device through the opening located above the surface of the ground of the upper tube part 20. Said mixture of fuel and oxygen upon having filled the whole heating device and reached the discharge tube 16 is ignited at that tube. Now, the velocity of the mixture of fuel and oxygen is adjusted so as to cause the flame to recede
i.e. to migrate in a backward direction relative the direction of flow of said mixture, said flame thus being displaced downwards within the inter space between the casing 10 and the inner tube 19, 20 and then upwards within the wider tube part 19. It is of essential importance that the linear flow velocity of the mixture is less than the linear propagation velocity of the flame which is dependent on, inter alia, the composition of the fuel. The cross-section of the narrower tube part 20 is dimensioned so as to cause the velocity of flow of the mixture to surpass the velocity of combustion thereof. This feature keeps the flame stationary in the conical part 21 and prevents it from proceeding further upwards towards the surface of the ground. The narrower portion 20 of the inner tube thus acts as a kind of flame trap.

If the flame should be extinguished after the heating device has been in operation for some time and the casing has become heated, an application of the ignition method just described is not suitable. At such occasions it has proved difficult to adjust the quantity of the mixture of fuel and oxygen so as to force the flame to proceed in the desired way. In such a case the ignition is preferably performed by introducing a burning body such as a rocket, for example, down into the device through the inner tube 19, 20. The rocket must be of such type as to be totally consumed without leaving any residue. During introduction of the rocket, the supply of the fuel-oxygen mixture is interrupted, but it must then be started again with a minimum of delay. This will result in an ignition of the mixture at the bottom of the casing 10 whereupon the flame will proceed upwards within the wider tube part 19 in a direction towards the narrower tube part 20. If the re-ignition must be done during such a period of the heating process as not to have caused the casing 10, there is a possibility of water having been collected in the lower part of said casing. In order to prevent the introduced rocket from becoming extinguished by said water, it may be suitable to provide a rocket-catch ing member 30 at a sufficient distance from the bottom of the casing 10. Said member 30 may be a nut located in such spaced relation to the stationary flame as not to be burnt and destroyed thereby.

The hot flue gases formed by combustion will flow through the wider tube part 19 toward the bottom of the casing 10. Thereafter, they are forced to turn and then to pass through the inter space between the casing 10 and the inner tube 19, 20 to escape finally through the discharge tube 16. The wider tube part 19 will consequently become heated most adjacent the conical part 21 and remain coldest at its lower end near the bottom of the casing 10. Due to their yielding of heat to the casing 10 the ascending flue gases will show an opposite distribution of temperature. By a combined effect of heat radiation and convection from the tube part 19 and heat transfer from the ascending flue gases, the total heat yielded to a unit of length will be approximately the same as far as that portion of the casing 10 is concerned which is located within the deposit 12. The heating of that portion of the casing, however, which is located on a higher level than the upper surface of the deposit 12, will remain insignificant, as any additional heat will not be yielded from the upper part 20 of the inner tube. On the contrary, the escaping flue gases will be cooled by the condensing fuel-oxygen mixture which in turn will be preheated. The conditions governing the heat yielding phenomena have been described in detail in the copending application Serial No. 377,952, filed September 1, 1953, which is referred to for a fuller explanation thereof. The means described in said application are open to the flow and for applying protection against radiation and heat insulating layers are applicable also to the device constructed in accordance with the present invention.

In the embodiment shown in Fig. 2 the inner tube 22 has equal diameter over its total length. A throttle flame 23 is located within said tube on a level coinciding with the upper boundary surface of the deposit 12. The velocity of flow of the mixture is considerably higher when the mixture passes through the narrow channel in flame 23 than below said flame 23, the flame is prevented from continuing its path upwards past the flame and will become stationary in the desired position coinciding with the upper boundary surface of the deposit 12.

Fig. 3 shows an embodiment comprising in the same manner as the embodiment according to Fig. 2 an inner tube 24 of equal diameter over its entire length, the throttling valve 23, however, having been replaced by a cylindrical body 25 having an external diameter somewhat less than the interior diameter of the tube 24. In this way, a narrow or restricted passage or channel is created along the interior wall of the inner tube, said passage or channel ensuring the desired throttling effect. The cylindrical body 25 may be made as a convenient flame trap, i.e. it may be of a type permitting passage of gas through its interior. For example, it may be a basket having a perforated bottom and being filled with a highly porous substance such as gravel, for example. It is essential only that the body have a throttling effect sufficient to create the required high velocity of flow of the fuel-oxygen mixture. The body 25 is suspended on a wire 26 allowing easy raising and lowering of the body and thereby causing the throttling effect on the fuel-oxygen mixture on any desired level within the tube 24. Due to the construction just described it will be a simple task to obtain heating of a predetermined larger or smaller portion of the casing 10. It is possible to start, for example, with the heating of a minor portion of the deposit 12 adjacent the stratum 11 and successively to widen said zone until the whole deposit 12 has become heated. When proceeding in this way the gaseous and liquid products formed during the heating process are driven upwards against the lime stone stratum 13 where they may be collected and recovered by means of specific outlet tubes.

A further device embodying the invention with a displaceable heating zone is illustrated in Fig. 4. In the same manner as in the embodiment shown in Fig. 1, the inner tube consists of a wider part 27, a narrower part 28 and to turn and then to pass through the inter space between the casing 10 and the inner tube 29, 30 to escape finally through the discharge tube 31. The wider tube part 27 will consequently become heated most adjacent the conical part 32 and remain coldest at its lower end near the bottom of the casing 10. Due to their yielding of heat to the casing 10 the ascending flue gases will show an opposite distribution of temperature. By a combined effect of heat radiation and convection from the tube part 29 and heat transfer from the ascending flue gases, the total heat yielded to a unit of length will be approximately the same as far as that portion of the casing 10 is concerned which is located within the deposit 12. The heating of that portion of the casing, however, which is located on a higher level than the upper surface of the deposit 12, will remain insignificant, as any additional heat will not be yielded from the upper part 30 of the inner tube. On the contrary, the escaping flue gases will be cooled by the condensing fuel-oxygen mixture which in turn will be preheated. The conditions governing the heat yielding phenomena have been described in detail in the copending application Serial No. 377,952, filed September 1, 1953, which is referred to for a fuller explanation thereof. The means described in said application are open to the flow and for applying protection against radiation and heat insulating layers are applicable also to the device constructed in accordance with the present invention.
The following specific example will illustrate more in detail the invention. A deposit of tar sand having a height of 40 metres is covered by a layer of a height of 10 metres and composed of lime stone, earth and gravel. Through said strata and further to a depth of 2 metres below the bottom of the tar sand deposit a vertical hole is bored from the surface to the level of the top of the deposit and of a diameter of 56 millimetres. The total depth of the borehole is thus 52 metres.

A heating device constructed according to Fig. 1, for example, is introduced into said hole. The casing 10 has a length of 53 metres, an exterior diameter of 47.5 millimetres and an interior diameter of 41 millimetres. The space between the wall of the hole and the casing 10 is filled with sand 15. The narrower part 20 of the inner tube has a length of 10.5 metres, an exterior diameter of 12 millimetres and an interior diameter of 8.25 millimetres. The wider lower tube part 19 has a length of 42.5 metres, an exterior diameter of 31 millimetres and an interior diameter of 27 millimetres.

A mixture of combustible gas and air is fed into the device from the surface of the ground through the narrower tube part 20. The gas has an effective heat value of about 4000 kcal. per cubic metre, and its approximate composition is:

- 25% of hydrogen,
- 35% of methane, ethane and ethylene,
- 40% of nitrogen.

Prior to ignition, the mixture is supplied with an intensity of 0.2 cubic metre of gas and 0.7 cubic metre of air per hour. Said mixture upon having occupied the entire device so as to reach the discharge tube 16 is ignited there. The flame will initially be displaced in a downward direction within the interspace between the casing 10 and the inner tube 19, 20 and subsequently in an upward direction through the wider tube part 19 to the conical part 21 where the flame will become parabolic. The quantity of supplied mixture is now successively increased to 7.5 cubic metres combustible gas and 26.5 cubic metres air per hour. The period of successive increase of the flow velocity of the gas mixture comprises about two hours, the proportion between the combustible gas and the air is maintained at the ratio of 1:1.5. Finally the quantity of supplied air is further increased to about 32 cubic metres of air supplied per hour, the proportion between the gas and the air thus being changed to 1:4.25.

The stationary combustion will yield a total heating effect of about 30,000 kcal. per hour to be distributed over a difference of level of 43 metres. The heat yielded will thus amount, when calculated for one metre of length of the heating device to about 700 kcal. per hour. The heating device constructed according to the invention is capable of developing considerably higher effects, but in a continuous operation the heat absorbing capacity of the surrounding deposit must also be taken into consideration. Said capacity depends, inter alia, on the heat transfer coefficient of the deposit consisting of tar sand, for example, and on the distance between individual heating devices introduced into the deposit.

The fuel required for the combustion may be a combustible gas, but also a liquid or finely divided solid fuel may be used together with or instead of gas. The necessary oxygen may be supplied either as pure oxygen or as an oxygen containing gas mixture such as air, for example.

We have more or less all the invention have been shown it is to be understood that this is for purpose of illustration only and that the invention is not to be limited thereby, but its scope is to be determined by the appended claims.

What we claim is:

1. A tubular heating device for heating sub-surface deposits in their natural location in the ground for recovery of valuable combustible products in liquid or gaseous form, heat being generated in a combustion zone for fuel inside the device when positioned in said deposit, said device comprising an external elongated tubular casing at its base and side walls sealed against the deposit and at its top provided with an outlet for the products of combustion projecting above the surface of the ground, and an internal unitary tubular structure located concentrically and longitudinally displacable within said external casing and including a fuel and oxygen supply casing adapted with its upper end extending to the surface to receive a mixture of fuel and oxygen, a combustion zone conical casing adjacent and merging into the lower end of said supply casing and adapted to receive said fuel and oxygen mixture, and a combustion products tubular casing at its top in open connection with said conical casing and having an open base end located in spaced relation from the closed base of said external casing so as to provide open communication between said combustion zone tubular casing and said external casing for the flow of combustion products from said combustion zone downwards through said combustion products tubular casing and in counter current upwards through the space between said internal unitary tubular structure and said external tubular casing to the outlet, said conical casing being or being connected to said fuel and oxygen supply casing at its reduced end so as to ensure a velocity of flow of said mixture to the combustion zone casing greater than the velocity of combustion in the zone of combustion.

2. A heating device as set forth in claim 1 in which the length of the combustion zone tubular casing together with the combustion products tubular casing corresponds approximately to the vertical dimension of the deposit.

3. A tubular heating device for heating sub-surface deposits in their natural location in the ground for recovery of valuable combustible products in liquid or gaseous form, heat being generated in a combustion zone for fuel inside the device when positioned in said deposit, said device comprising an external elongated tubular casing at its base and side walls sealed against the deposit and at its top provided with an outlet for the products of combustion projecting above the surface of the ground, an internal tubular open at its lower end located eccentrically within said casing and substantially coextensive therewith, said open end being spaced from the base of said casing, said tube having gas restriction means therein above its open end defining a fuel and oxygen supply zone thereabove, an ignition zone adjacent said restriction means, and a combustion products zone adjacent said open end, said products of combustion issuing from said open end and circulating upwardly through the space defined between said tube and said casing to said outlet, said space being dimensioned to maintain a flame formed upon ignition of a mixture of fuel and oxygen introduced from outside into the device in such quantity to fill the device and to penetrate out of said discharge outlet in a burning state while proceeding in a direction opposite to that of the flow of the mixture to a predetermined point adjacent said restriction means within the device.

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