Feb. 24, 1959 H. J. TADEMA 2,874,777

PRODUCING PETROLEUM BY UNDERGROUND COMBUSTION

Filed July 14, 1955

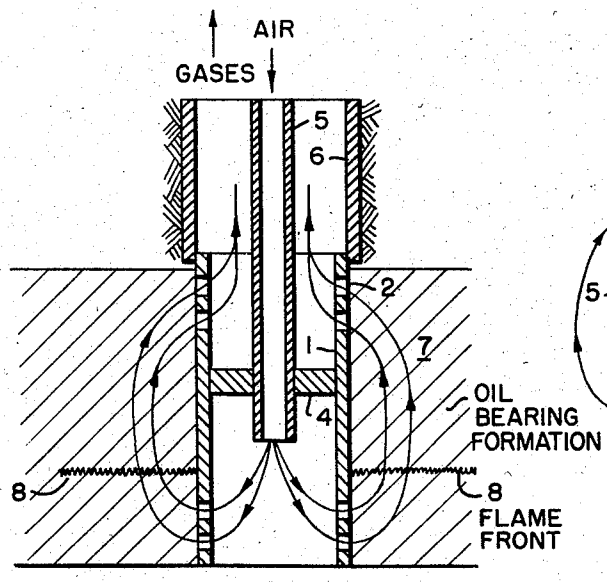


FIG. 1

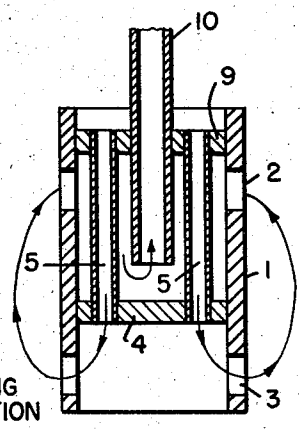


FIG. 2

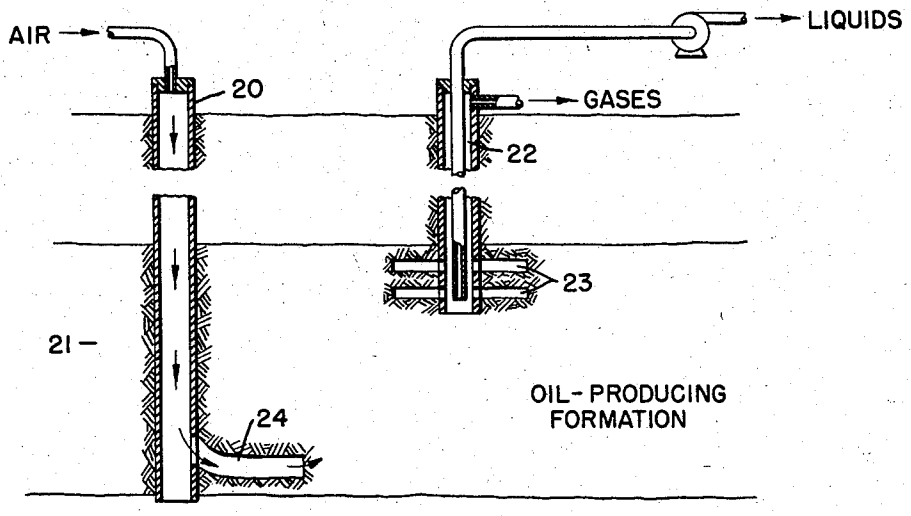


FIG. 3

INVENTOR

HARCO J. TADEMA

BY J. H. McCarthy

HIS AGENT

United States Patent Office 2,874,777
Patented Feb. 24, 1959

2,874,777

PRODUCING PETROLEUM BY UNDERGROUND COMBUSTION

Harco J. Tadema, Amsterdam, Netherlands, assignor to Shell Development Company, New York, N. Y., a corporation of Delaware

Application July 14, 1955, Serial No. 522,011

Claims priority, application Netherlands July 19, 1954

5 Claims. (Cl. 166—11)

The invention relates to the production of oil and pertains more particularly to a process and apparatus for carrying out underground combustion in an oil-bearing formation for the purpose of producing petroleum, in which a part of the combustible material (oil, oil residue, tarry substances, etc.) originally present in the oil-bearing formation is burnt.

It has previously been proposed to produce oil, in particular highly viscous oil, by the use of a method commonly known as underground combustion. One of the great difficulties arising in this method of production is the maintenance of a regular displacement of the combustion front in the oil-bearing formation. It was only rarely possible to cause the combustion front to travel over more than a short distance in a horizontal direction without it being necessary time and again to re-start the combustion.

It is therefore an object of this invention to provide a method of causing combustion in an oil-bearing formation to proceed more uniformly, thus reducing the risk of untimely interruption of the combustion.

Another object of this invention is to provide a method wherein underground combustion is conducted in such a way that the combustion zone progresses upwards through the formation or a part thereof in a more or less vertical direction from below.

A further object of this invention is to provide a method and apparatus for carrying out underground combustion in an oil-bearing formation, wherein a single well is employed for introducing air to the combustion zone while simultaneously removing produced fluids from the well.

These and other objects of this invention will be understood from the following description taken with reference to the drawings, wherein:

Figure 1 is a diagrammatic view in cross section of the lower portion of a well provided with equipment for carrying out the present method of underground combustion.

Figure 2 is a diagrammatic view in cross section of another form of apparatus for use according to the present invention.

Figure 3 is a diagrammatic view, partly in section, of an oil field, showing an apparatus by which the method of invention is practiced.

A particularly suitable embodiment of the invention is that in which the gases giving off oxygen which is required for the combustion (hereinafter referred to as air) are led into a given well and introduced at the bottom of the oil-bearing formation, while gases from the combustion zone are withdrawn separately through the same well at the top of the oil-bearing formation, as shown in Figure 1. Thus, in this process only a part of the formation is generally worked per well.

The process may also be carried out by means of two wells situated near each other, as illustrated in Figure 3. The air is led into one well **20** and injected at the bottom

of the oil-bearing formation **21**, while gases originating from the combustion zone are removed from the other well **22** at or near the top of the formation. In carrying out this process it is possible to use a number of "input" wells and/or a number of output wells, e. g., an input well surrounded by a number of output wells. The distance from an input well to an output well must preferably not be too great (taking into account the depth of the oil-bearing formation) if the combustion is to proceed as desired mainly in a vertical direction. The greatest distance is approximately 2 to 3 times the depth of the oil-bearing layer. Preferably, however, this distance is not to exceed the depth of the layer.

If the oil-bearing formation shows a steep slope (approximately 20° or more), the desired movement of the combustion zone in a vertical direction may be obtained by causing the combustion to start (by introducing air) at a well which penetrates the oil-bearing formation at a lower level (preferably as low as possible) and by removing the combustion gases from one or more wells penetrating the formation at a higher level. In this case it is not always necessary (although highly advisable) to inject air only at the bottom of the formation and/or to remove the combustion gases only at the top of the formation.

The present process is preferably carried out with one or more wells in which, at the top and/or at the bottom of the oil-bearing formation, one or more holes or passages are provided in a lateral direction, e. g., by drilling or shooting.

Preferably a system of passages **23** and **24** (Figure 3) is used for each well (e. g., a number of radial passages or holes) at the top and/or at the bottom of the formation. The combustion according to the invention can then be carried out in the space between these systems, the latter being situated directly or obliquely above each other in a vertical direction. In this case it is possible to use the same well as the injection well and also as the output well; however, a number of separate injection and output wells may also be used. In the latter case the wells need not be situated close to each other, provided the passages extend sufficiently in a lateral direction.

By providing the lateral holes or passages, the starting and maintenance of an underground combustion front through the formation in a substantially vertical direction from below to above is greatly facilitated. The passages may be drilled or shot horizontally, although this is not essential. In a sloping layer the holes are preferably provided parallel to this layer.

The difficulties which occur in the conventional process of underground combustion, in which the combustion zone moves solely or chiefly in a horizontal direction, are probably due to the oil (the viscosity of which is reduced as a result of the temperature increase occurring) settling in the formation. Owing to the settling of the oil, the combustible material disappears from the combustion site within the formation, and the combustion stops.

In the present process, however, a more or less uniform supply of oil to the combustion zone will be obtained. If, for example, oil should entirely evaporate at any place as a result of the combustion heat, the vapors will rise, condense in a colder layer situated higher up, and subsequently part of the condensed oil will flow back again to the combustion zone. This tends to set up an equilibrium condition in which there is just sufficient fuel in the combustion zone for the combustion. Formations with relatively volatile oil which formerly caused the greatest difficulties, can be successfully opened up in the manner according to the invention.

In order to support the combustion, air is usually

forced into the injection well, although it is also possible to use other gases, such as oxygen itself, oxygen-containing gases, nitrogen dioxide, etc.

The use of the present process with a single well, which is particularly suitable if the oil-bearing formation has a considerable layer thickness (approximately 10 m. or more), also has the advantage that each injection well also functions as a production well, so that it is not necessary to drill additional production wells.

Part of the oil present in situ is cracked and/or evaporated by the combustion occurring in the formation, while the hot combustion gases increase the temperature of the formation in the neighborhood of the combustion zone and consequently reduce the viscosity of the oil.

As a result of the difference between the pressure of the air injected and the pressure at the place where the combustion gases are withdrawn (preferably by suction), the combustion front moves through the formation in a more or less vertical direction from below to above, thus making it possible to produce a part of the oil present in the formation.

If the same well is used as injection well for the air and also as output well for the combustion gases, the oil generally flows into the well at the top of the formation and in this way it is possible to produce it in any suitable manner, as by pumping.

When different wells are used for supplying the air and removing the combustion gases, the oil will often not only flow to the top of the output well but also (sometimes exclusively, as may occur, for instance, in carrying out the process in a sloping formation) to the bottom of the output well. The oil which collects there can then also be produced, e. g., by pumping up.

In practicing the present production method on a single well a special well liner is employed. This liner is provided with openings (e. g., slots) in the wall only at the top and the bottom; a packer with at least one opening, to which a hollow tube can be connected, is provided internally between the top and the bottom openings. This tube may serve to supply the air required for the combustion when the liner is used in an injection well. If the liner is used in a production well (when working with separate injection and production wells) the oil which collects at the bottom of the well can be pumped up via this tube.

Referring to Figure 1 of the drawing, a liner **1** is shown which is provided with openings **2** (at the top) and **3** (at the bottom). Between these openings a packer **4** is arranged through which a hollow tubing string **5** passes. Figure 1 also shows a well casing **6**, as well as an oil-bearing formation **7** and a combustion front **8** adjacent the well.

The air required for the combustion is supplied from the surface through the hollow tubing string **5** and is forced into the formation via the openings **3**. The combustion gases are withdrawn, e. g., by suction, through the openings **2** on the top of the liner. The stream of air and gas is shown in the drawing by means of arrows. The combustion front **8** slowly moves in a vertical direction, thereby expelling oil before it. This oil will also flow through the openings **2** into the space above the packer **4** and can be removed therefrom, e. g., by pumping.

If the combustion shows a tendency to limit itself to a small zone around the liner, the combustion front can be further extended laterally by injecting at some place between the combustion zone and the top of the formation a substance which more or less seals off the formation at the place, or hinders or prevents the combustion at this place. This substance may consist, for example, of a cement slurry, a drilling mud or water.

Such an injection can be generally made when it is desired to make the combustion zone progress in a certain direction.

Figure 2 shows another construction of the liner. The packer **4** has a number of openings (two in the drawing) to which the tubes **5** are connected, through which the combustion air is supplied. The combustion gases and the oil produced can be withdrawn via a central tubing string **10**. The liner is sealed at the top by means of a second packer **9** through which the tubes **5** and the tube **10** are passed. The pumping installation for lifting the oil can now be conveniently arranged in a central position within the tubing string **10**, if desired.

The liner shown in Figure 1 can also be used in a production well in the process with separate injection and production wells. In this case the oil collected at the bottom of the well can be lifted or pumped out via the hollow tube **5**, while the combustion gases are separately removed via the openings **2**.

I claim as my invention:

1. A method for carrying out an underground combustion in an oil-bearing formation which is penetrated by at least one well for the purpose of producing fluids therefrom, the steps of establishing communication between the bottom of said oil-bearing formation and the ground surface through a first conduit, establishing communication between the top of said oil-bearing formation and the ground surface through a second conduit, forcing under pressure an oxygen-containing gas into the bottom portion of said oil-bearing formation through the first conduit, initiating and maintaining combustion at the bottom of said oil-bearing formation to heat the oil therein and drive the components of said oil in a substantially vertical direction toward the top of said formation, a part of the combustible material originally in said oil-bearing formation being burned as the combustion zone moves in a substantially vertical direction, and withdrawing the volatile unburned components of the oil from the top of said formation through the second conduit.

2. A method for carrying out an underground combustion in an oil-bearing formation which is penetrated by at least one well for the purpose of producing fluids therefrom, the steps of establishing communication between the bottom of said oil-bearing formation and the ground surface through a first conduit, establishing communication between the top of said oil-bearing formation and the ground surface through a second conduit forming a first series of lateral channels radially extending from said well near the top of said oil-bearing formation, forming a second series of lateral channels radially extending from said well near the bottom of said oil-bearing formation, closing the well around said conduits at a point intermediate the top and bottom of said oil-bearing formation, forcing under pressure an oxygen-containing gas into the bottom portion of said oil-bearing formation through the first conduit, initiating and maintaining combustion at the bottom of said oil-bearing formation to heat the oil therein and drive the components of said oil in a substantially vertical direction toward the top of said formation, a part of the combustible material originally in said oil-bearing formation being burned as the combustion zone moves in a substantially vertical direction, and withdrawing the volatile unburned components of the oil from the top of said formation through the second conduit.

3. A method for carrying out an underground combustion in an oil-bearing formation which is penetrated by at least two wells for the purpose of producing fluids therefrom, the steps of establishing communication between the bottom of said oil-bearing formation and the ground surface through one well, establishing communication between the top of said oil-bearing formation and the ground surface through a second well, forcing under pressure an oxygen-containing gas into the bottom portion of said oil-bearing formation through the first well, initiating and maintaining combustion at the bottom of said oil-bearing formation to heat the oil therein and drive the components of said oil in a substantially vertical direc-

tion toward the top of said formation, a part of the combustible material originally in said oil-bearing formation being burned as the combustion zone moves in a substantially vertical direction, and withdrawing the volatile unburned components of the oil from the top of said formation through the second well.

4. A method for carrying out an underground combustion in an oil-bearing formation which is penetrated by at least two wells for the purpose of producing fluids therefrom, the steps of establishing communication between the bottom of said oil-bearing formation and the ground surface through a first well, establishing communication between the top of said oil-bearing formation and the ground surface through a second well forming a first series of lateral channels radially extending into said formation near the bottom of said first well, forming a second series of lateral channels radially extending into the formation near the bottom of said second well, forcing under pressure an oxygen-containing gas into the bottom portion of said oil-bearing formation through the first well, initiating and maintaining combustion at the bottom of said oil-bearing formation to heat the oil therein and drive the components of said oil in a substantially vertical direction toward the top of said formation, a part of the combustible material originally in said oil-bearing formation being burned as the combustion zone moves in a substantially vertical direction, and withdrawing the volatile unburned components of the oil from the top of said formation through the second well.

5. A method for carrying out an underground combustion in an oil-bearing formation which is penetrated by at least one well for the purpose of producing fluids therefrom, the steps of establishing communication between the bottom of said oil-bearing formation and the ground surface through a first conduit establishing communication between the top of said oil-bearing formation and the ground surface through a second conduit, forcing under pressure an oxygen-containing gas into the bottom portion of said oil-bearing formation through the first conduit, initiating and maintaining combustion at the bottom of said oil-bearing formation to heat the oil therein and drive the components of said oil in a substantially vertical direction toward the top of said formation, a part of the combustible material originally in said oil-bearing formation being burned as the combustion zone moves in a substantially vertical direction, injecting a non-combustible material radially into said formation at a point intermediate the top and bottom thereof to hinder combustion adjacent the well, and withdrawing the volatile unburned components of the oil from the top of said formation through the second conduit.

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