United States Patent

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[33] **Canada**
[31] **43,671**

[54] **METHOD OF RECOVERING HYDROCARBONS FROM AN UNDERGROUND HYDROCARBON CONTAINING FORMATION**
2 Claims, 2 Drawing Figs.

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[51] Int. Cl. E21b 43/24
[50] Field of Search 166/272, 302, 303, 263, 251, 252, 256

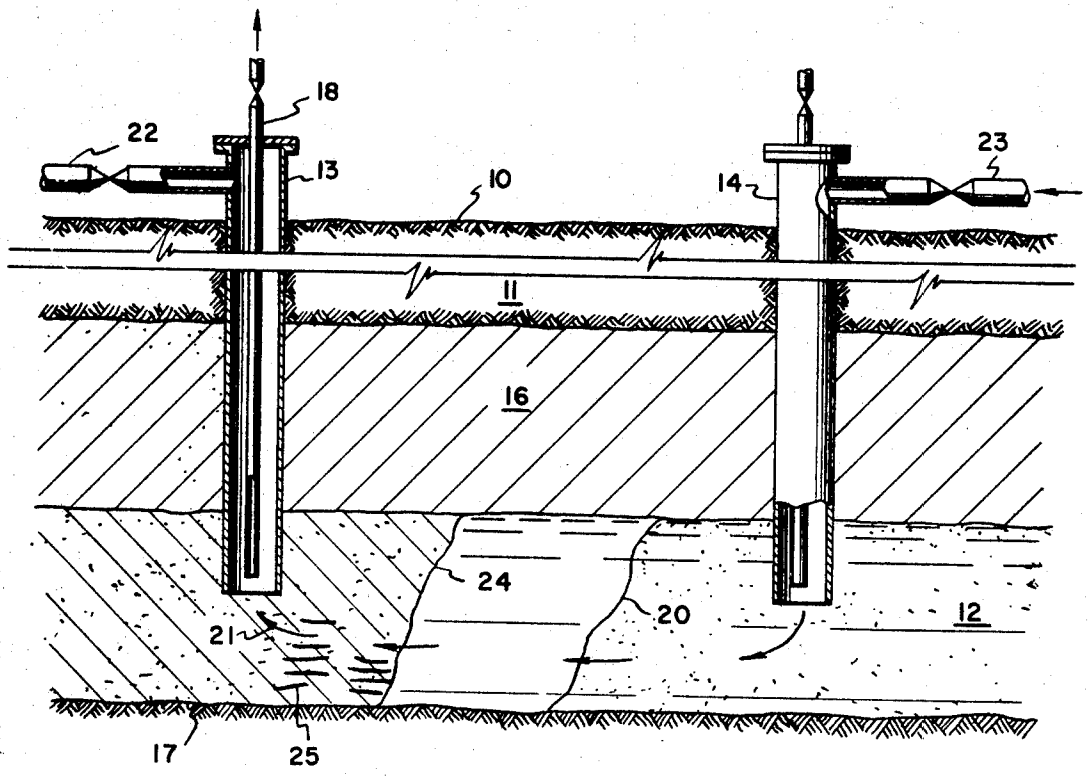
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ABSTRACT: An improved method for oil recovery from a formation using a combination of steam and in situ combustion drives comprising injecting steam via an injection well, followed by injecting a combustible gas via a production well and thereafter recovering oil via the injection well.



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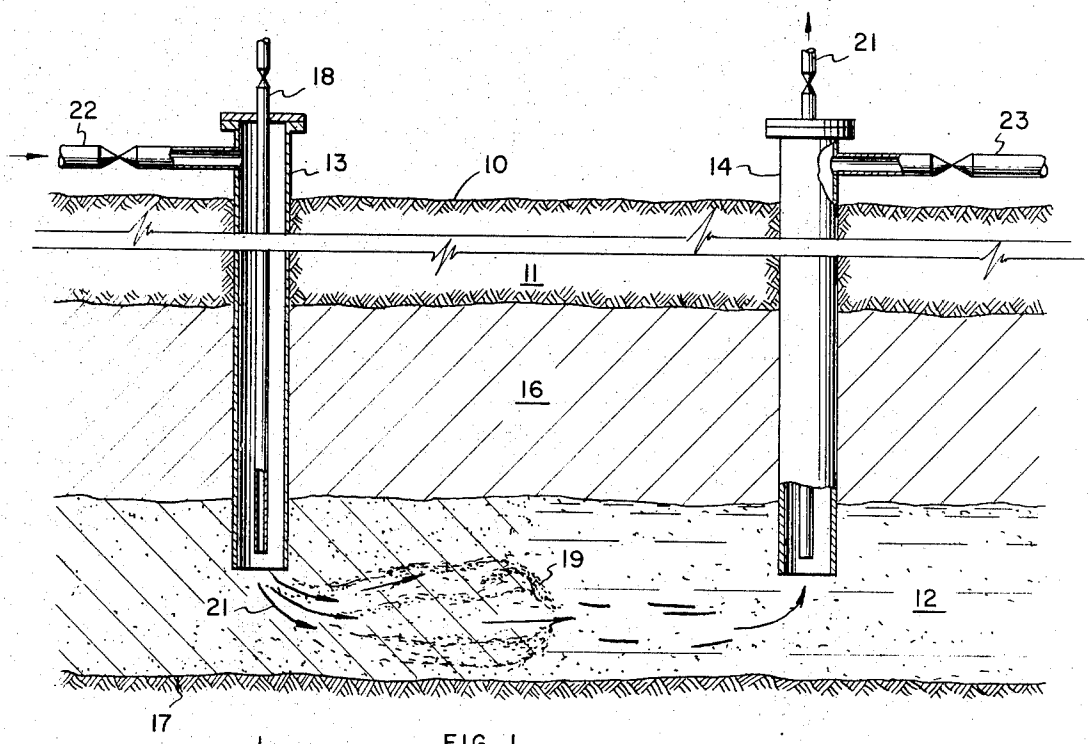


FIG. 1

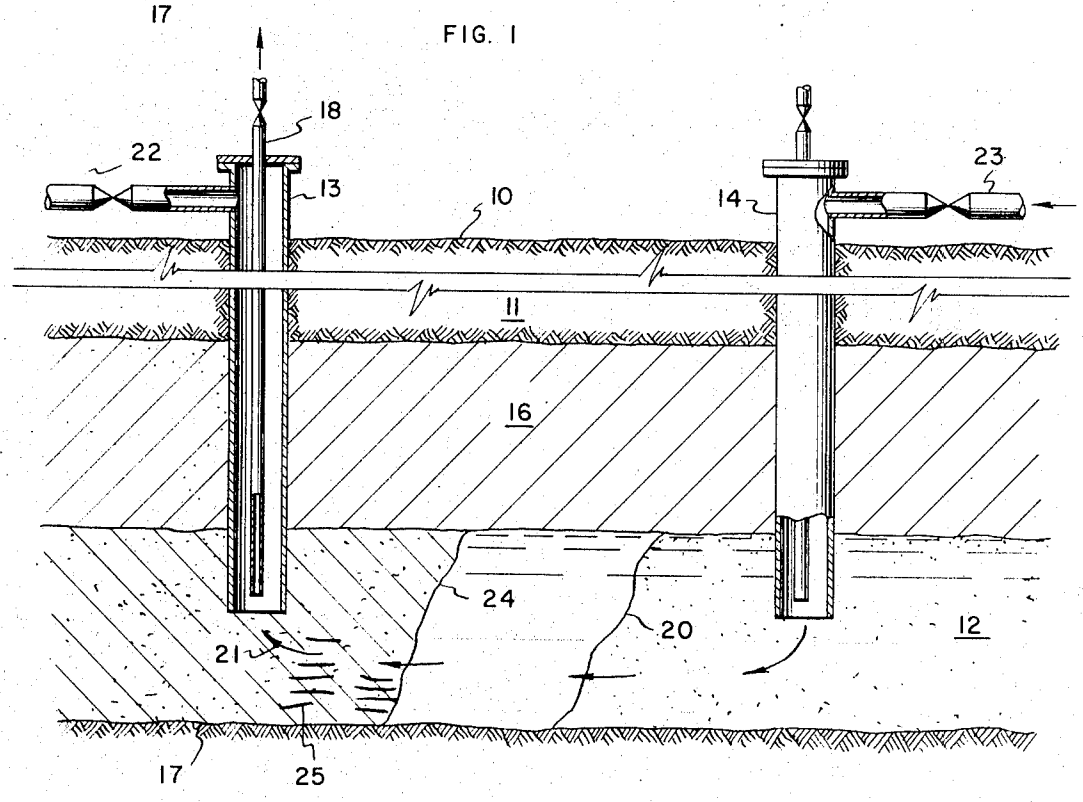


FIG. 2

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METHOD OF RECOVERING HYDROCARBONS FROM AN UNDERGROUND HYDROCARBON CONTAINING FORMATION

BACKGROUND OF THE INVENTION

The present invention relates to a method of recovering hydrocarbons from an underground hydrocarbon-containing formation by thermal means. In such methods, heat is applied to the formation so as to reduce the viscosity of the hydrocarbon present in the pores of the formation to enable or improve the drainage of these hydrocarbons so as to facilitate oil recovery.

The heat required for the desired viscosity reduction of the hydrocarbon can be generated in situ by injecting oxygen-containing gas into the pores of the formation, which gas causes combustion of part of the hydrocarbon present within the formation. The water vapor generated during this reaction condenses against the cold parts of the formation, thereby forming a condensation front which heats the hydrocarbon and drives it towards the production wells. A drawback of this method is the high cost of compressing the oxygen-containing gas to a suitable pressure before injecting it into the formation.

In another thermal method, a hot fluid such as hot water, steam or another condensible gas is injected into the pores of the formation. The hot fluids heats the hydrocarbon and then displaces the hydrocarbon through the pores of the formation to the production wells. In this method, the cost involved per unit of enthalpy supplied to the formation is less than the cost involved in the above-mentioned in situ combustion method. A drawback of this method, however, is the loss of heat to the part of the formation being treated, as well as the loss of heat to the cap rock and the base rock, which losses may become unacceptable near the end of the operation, in particular if there are great distances between the individual wells.

Still another method of thermal oil recovery comprises injecting into a formation from which oil is to be recovered via an injection well a hot fluid followed by injecting through the same well an oxygen-containing gas in order to establish a combustion front so as to drive oil to a production well to recover oil therefrom. However, in this process the oil recovery path established by this system and fluid flow is difficult to control thus decreasing the efficiency of oil recovery.

EMBODIMENT OF THE INVENTION

In accordance with the present invention these disadvantages of the known methods are reduced or eliminated, and a high recovery of hydrocarbons from a hydrocarbon-containing underground formation can be achieved at relatively low compression costs and with relatively low heat losses.

According to the invention the method of recovering hydrocarbons from an underground, hydrocarbon-containing formation comprises the following steps:

1. arranging at least two wells penetrating into the formation and communicating with the pores of the formation,

2. injecting via one or more of the injection wells into the pores of the formation unsaturated, saturated or supersaturated steam into the unheated parts of the formation under the conditions of operation, until a portion of the hydrocarbon has been mobilized or fluidized,

3. after the cessation of such injection, injecting via one or more production wells an oxygen-containing gas so as to create an in situ combustion front, and

4. recovering hydrocarbon alternately through the production well(s) and then the injection well(s) during the sequence of the steps (2) and (3).

Preferably, the injection of the steam in step 2 is stopped after at least 50 percent of the pore volume in the part of the formation to be treated has been heated by the steam.

The steam may be injected over the entire height of the hydrocarbon-containing formation or only at a particular level. In general, it will be preferred to inject the steam at a level near the lowest part of the formation.

It is also preferred that the steam injection in step 2 is injected at the lowest practical pressure. The water that is formed by steam condensation during the steam injection step aids in controlling the later in situ combustion resulting from the oxygen-containing gas (air) injection, as well as total heat utilization.

The invention will now be described, by way of example, with reference to the accompanying drawing, which show schematically a vertical section of part of the earth's crust including a hydrocarbon-containing formation, and injection and production wells. In this formation, the mobility of the hydrocarbon present in the pores is sufficiently low that it cannot be recovered in the most economic manner under influence of its own energy or by the aid of pumping equipment installed in the wells. The mobility is, furthermore, sufficiently low that the application of a cold fluid drive is not economically feasible. Such hydrocarbon has hitherto only been economically recoverable, if at all, by a thermal method.

DESCRIPTION OF THE FIGURES

In FIGS. 1 and 2 from the surface 10 and through the layers 11 and 16 overlying the hydrocarbon-containing formation 12, there are drilled two wells 13 and 14, which penetrate into the formation 12. The wells are drilled and completed in a manner known per se, and for sake of simplicity all details such as casing, tubing, wellhead, cementing layers, liners, etc. are omitted from the drawing and description. One of the wells 13, is designed as an injection well for injecting steam for heating the contents of the formation 12 and from which oil is to be recovered via tubing string 18. The other well, 14, is designed as a production well from which oil is to be recovered via tubing string 21 and via which a combustible gas, e.g., air is injected to establish in situ combustion. Although the formation 12 is shown in the drawing substantially horizontal, it will be understood that the method of the invention may be applied with similar results to hydrocarbon-containing formations which are of the slanted type. The cap rock 16 which forms part of the overlying layers with 11 as well as the base rock 17, are substantially or entirely impermeable.

SPECIFIC DESCRIPTION OF THE EMBODIMENT OF THIS INVENTION

In accordance with the invention, there is first injected steam via injection well 13 via valved line 22 into the pores of the formation as shown in FIG. 1. This steam may be either wet, dry or superheated. If desired, a hydrocarbon may be mixed with the steam for increasing the recovery efficiency.

The injectivity of the steam into the formation 12 may be increased in the neighborhood of the well 13, by any of the methods known in the art.

The steam is obtained from any convenient source (not shown), and must of course be at a pressure higher than the formation pore pressure, this steam is conducted under this pressure into the top of the well 13 via valved line 22. If desired, bleedwater from a boiler supplying the steam may also be injected into the well 13. This has the advantage that salts concentrated in the residue water are removed from the boiler without loss of heat. These will be removed from the boiler if wet steam is employed for injection.

The injection of steam into the formation 12 is stopped after at least 50 percent of the pore volume of the part of the formation to be treated has been heated. This means in practice that the amount of injected steam is more than 0.5 to 2 times the pore volume measured as steam condensate. It is to be understood that the part of the formation treated is that part of the formation arranged between the injection well(s) and the production well(s), and which is, during the application of the method of the invention, sufficiently heated to allow the hydrocarbon to flow therefrom to the production well(s) or injection well(s). The mechanism causing such hydrocarbon flow is derived from said injection.

During injection of the steam, condensation occurs against the relatively cold hydrocarbon forming a condensation front **19** which, under the influence of further steam injection, travels in the direction of the production well **14**, with the aid of pumps or the like. All of the formation between the injection well **13** and condensation front **19** has been treated and much of the hydrocarbon therein swept out to the production well **14**. It is not necessary to the practice of this invention that the full vertical section of formation **12** be swept by the condensation front **19** during this step.

After the desired amount of steam has been injected into the pores of the formation **12**, this injection is stopped, and in place thereof compressed air or other oxygen-containing gas such as air is pumped into the pore space of the formation **12** via production well **14** through valved line **23** where the temperature conditions enable spontaneous combustion to take place wherever the oxygen-containing gas comes into contact with sufficiently great amounts of hot hydrocarbon. In this way, as shown in FIG. **2**, a combustion front **20** is formed, which travels in the direction of the injection well **13**, and by virtue of vaporization and subsequent condensation of water already present in the formation and of water created by the combustion also forms a condensation front **24** which travels ahead of the combustion front **20** towards the injection well **13**. Hydrocarbons are heated by the condensation of steam to water and are mobilized, then caused to flow to the injection well **13** through the heated and depleted path **25** established during the steam injection step.

The present process encompasses a bidirectional injection scheme whereby steam drive between well **13** and well **14** is alternated with forward combustion between well **14** and well **13** after steam drive from well **13** to well **14**. On the other hand, the process described in U.S. Pat. No. 3,409,077 provides for cyclic steam drive/forward combustion with both steam and air injection conducted in one direction only. The advantages of the present invention is that there is always provided during the combustion phase a well developed heated and depleted path through which the mobilized hydrocarbons, e.g., tar can move. This is a better path than that developed in a monodirectional system as described in the art mentioned above as the depletion and heating is most intense at the combustion phase production well. The bidirectional system of the present invention thus gives added assurance that fluid flow retardation through cooling of the hydrocarbons, e.g., tar will not occur. The second advantage of the present process is that air is injected towards the main heated area rather than through this area. This method assures that air contacts tar or other hydrocarbons at the outer edge of the heated zone and combustion occurs at the point where the heat can be most beneficial. Most of the oxygen available for combustion is consumed at that point, any remaining oxygen is reacted with residual tar in the heated zone thus avoiding hazardous oxygen breakthrough into the production well. Where the hydrocarbon is sufficiently viscous, several alternate "passes" of steam and combustion to and from a particular well may be required until the heat has risen to the top of the formation.

Although in the example described with reference to the drawing only two wells have been shown for carrying out the method according to the invention, the present invention is by no means limited thereto. Any number of wells and any type of well pattern may be used.

I claim:

1. Method of recovering hydrocarbon from an underground hydrocarbon-containing earth formation containing hydrocarbon in a substantially nonmobile state at ambient temperature, consisting essentially of the following steps:

1. arranging at least two wells of which one is an injection well and one is a production well penetrating into said formation and communicating with the pores thereof;
2. injecting steam through one of the injection wells into the pores of the formation until at least 50 percent of the pore volume of the part of the formation to be treated has been heated sufficiently to cause the hydrocarbon to flow toward the production well;
3. stopping injection of steam of step (2) and injecting through a production well an oxygen-containing gas to create an in situ combustion front of hydrocarbon and thereby establishing a bidirectional flow; and
4. recovering hydrocarbon alternately through the production well and injection well respectively in the sequence of steps (2) and (3).

2. Method as claimed in claim **1**, wherein the oxygen-containing gas in step (3) is air.