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[54] **METHOD OF IN SITU COMBUSTION WITH INTERMITTENT INJECTION OF VOLATILE LIQUID**
6 Claims, 1 Drawing Fig.

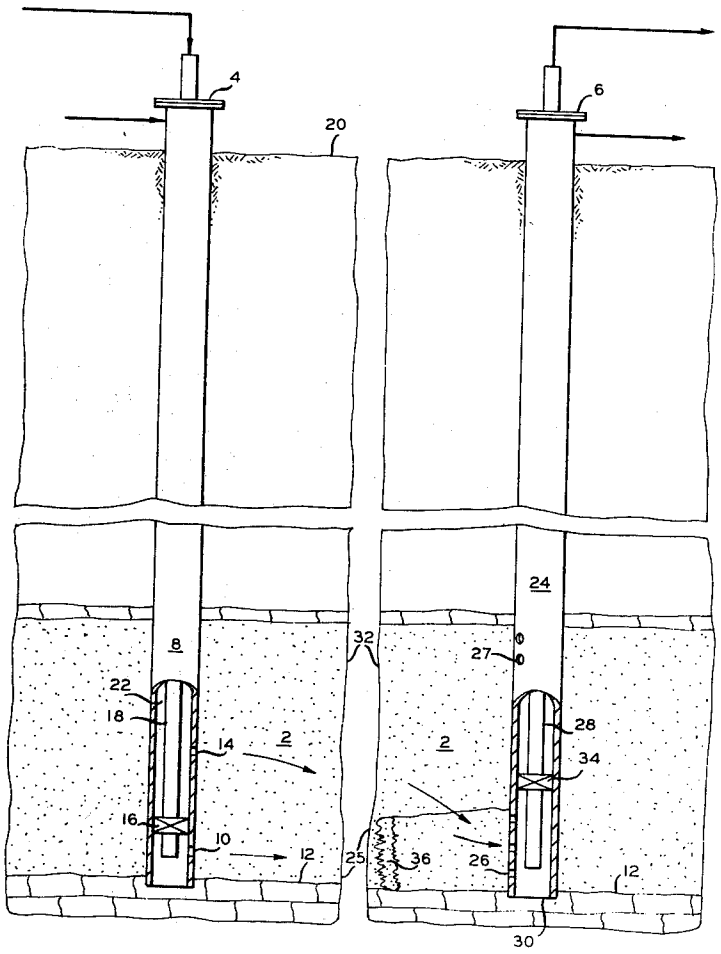
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[50] **Field of Search** 166/256-262, 269, 272

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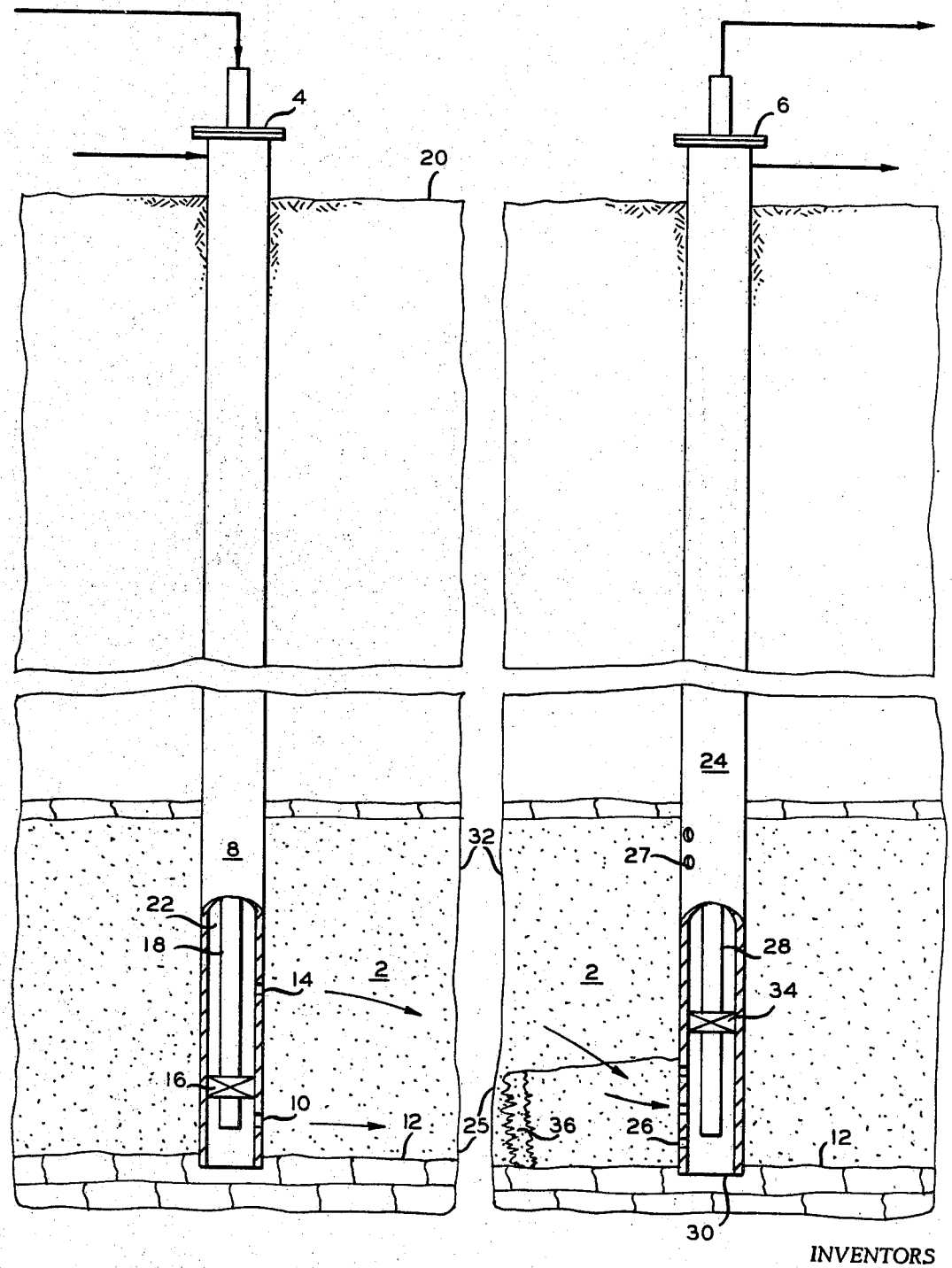
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ABSTRACT: A method of repeatedly heating the formation by alternately conducting in situ combustion in the lower portion of the formation and injecting a volatile hydrocarbon liquid into the heated zone to increase heat transfer and dilute the inplace hydrocarbons. Inert gas may be injected into the upper portion of the formation during combustion, and accumulated gases produced through upper perforations of the production well.



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METHOD OF IN SITU COMBUSTION WITH INTERMITTENT INJECTION OF VOLATILE LIQUID

This invention relates to a thermal recovery method for recovering hydrocarbons from a subterranean formation. In another aspect, this invention relates to a method of recovering hydrocarbons having a high viscosity from a subterranean formation.

In the recovery of oil from subterranean formations, there have been substantial advances in recovery methods so as to substantially increase the recovery of oil. However, appreciable quantities of oil remain in reservoirs after the termination of existing methods and in spite of such advances. Indeed, it is estimated that only about 30 to 50 percent of the oil in most reservoirs can be economically recovered by present techniques. Thus, there continues to exist a great interest in improving oil recovery methods.

One class of methods for recovering oil from underground reservoirs comprises in situ combustion methods. These methods in one embodiment involve the establishment of a combustion methods. These methods in one embodiment involve the establishment of a combustion front within a reservoir in the vicinity of one or more injection wells and the subsequent introduction of a combustion-supporting gas behind the combustion front in order to move the combustion front to the reservoir toward one or more production wells. As the combustion front advances, heat liberated by the front results in the vaporization of oil from a high temperature zone preceding the front. Cracking of oil, formation of coke or heavy liquid hydrocarbons may also occur. Oil vapors formed by the process are carried forward with combustion products and are condensed in cooler portions of the reservoir. Heat transfer to cold oil in sections of a reservoir in front of and around the advancing high temperature zone leads to a reduction in viscosity of oil and facilitates in displacement from a reservoir. Admixture of oil and gases is withdrawn from a reservoir at the production well.

Although the present in situ combustion methods of oil recovery are promising, there exists some disadvantages associated with them. One such disadvantage is that a combustion front and its associated high temperature region gravitates to the top of an oil-bearing formation as a result of gas-oil density differences. This leads to channeling and bypassing of a large portion of the inplace hydrocarbons. In hydrocarbon-containing formations which have high viscosity inplace liquids and tars, channeling of portions of the in situ combustion zone is increased and heat transfer to adjacent portions of the formation is restricted by the heavy hydrocarbons.

It is therefore an object of this invention to provide an improved method for in situ combustion for thermal recovery of hydrocarbons from a subterranean formation. Another object of the invention of the above-described type is to provide a method for decreasing the channeling of the combustion zone. Yet another object of the invention of the above-described type is to provide a method for increasing the transportation of heat from the combustion zone through the adjacent hydrocarbon-containing formation. A further object of this invention of the above-described type is to provide a method for diluting the viscosity of the inplace hydrocarbons. Other aspects, objects, and advantages of the present invention will become apparent from a study of the disclosure, the appended claims, and the drawing.

The drawing is a diagrammatic front view in partial section of a hydrocarbon-containing formation and the equipment utilized in the recovery method of this invention.

The drawing shows a subterranean hydrocarbon-containing formation **2** penetrated by an injection well **4** and a remotely located production well **6**. The injection well has casing **8** set through the hydrocarbon-containing formation **2**, thereafter referred to as the producing formation, with said casing **8** cemented at least through the producing formation **2**. The casing **8** is perforated or opened into the formation with lower perforations **10** adjacent the bottom **12** of the formation **2** and upper perforations **14** preferably positioned at a higher elevation than the lower 50 percent of the thickness of the formation **2**. A conventional injection packer **16** is positioned in the casing **8** of the injection well **4** between the upper and lower perforations **14, 10**. Injection tubing **18** is installed in the injection well **4** from the surface **20** through the packer **16** to a location adjacent the lower perforations **10**. The injections well **4** is thereby equipped for separate injection of fluids through the annulus **22** formed between the casing **8** and the tubing **18** and outwardly through the upper perforations **14** and into the producing formation **2** and through the tubing **18**, the lower perforations **10** and into the lower portion **25** of the producing formation **2**.

The production well **6** has casing **24** set through and cemented to the producing formation **2** with perforations **26** opening the casing **24** into communication with said formation **2** adjacent the lower portion **25** of said formation **2**. Production tubing **28** is installed through the casing **24** and positioned near the bottom **30** of the production well **6**. As described later, separate perforations **27** are preferably formed through the casing **24** of the production well **6** adjacent the upper portion **32** of the formation **2** with a production packer **34** surrounding the production tubing **28** and positioned between the perforations **26, 27** of said production well **6**.

In the operation of the thermal recovery method of this invention, as in situ combustion zone **36** is established in only the lower portion **25** of the producing formation **2** by methods well-known in the art. The producing formation **2** is thereafter heated by advancing the combustion zone **36** through the formation **2** and fluids entering the production well **6** through the lower perforations **26** are produced through the tubing **28** and recovered at the surface **20**.

In permeable formations it is preferred that the combustion zone be established adjacent the production well **6** and oxygen be supplied through the injection well **4** to establish conventional countercurrent in situ combustion within the formation **2**. If, however, the inplace hydrocarbons comprise fractured tar sands and other highly viscous inplace hydrocarbons it is preferred that the combustion zone **36** be established adjacent the injection well **4** and oxygen be supplied through the injection well **4** to establish conventional direct in situ combustion within the formation **2**. Since the only difference in this invention between the countercurrent and direct in situ combustion methods is the direction of movement of the combustion zone **36** and the area swept by the combustion zone **36**, and since both in situ methods are conventional and well-known in the art, only the countercurrent method is shown for illustrative purposes in the drawing.

Irrespective of whether using a direct or countercurrent in situ production method, the formation is heated by advancing the combustion zone through the formation tube by supplying oxygen to the combustion zone. In order to maintain the combustion zone **36** in only the lower portion **25** of the formation **2** in order to restrict channeling and improved hydrocarbon recovery, the oxidant for the combustion zone **36** is supplied through the lower perforations **10** of the injection well **4**. That oxidant can be supplied in the form of oxygen or air. If oxygen is the selected oxidant used in this invention, then air, natural gas, or inert gas should be injected downwardly through the casing **8**, outwardly through the upper perforations **14** and through the upper portion **32** of the formation **2** to cause the oxidant for combustion to be maintained in the lower portion **25** of the formation **2** thereby moving the combustion zone **36** through only the lower portion **25** of the formation **2**. If air is selected as the oxidant in this invention, then natural or inert gas should be injected through the upper perforations **14** of the injection well **4** to cause the oxygen for combustion to be maintained in the lower portion **25** of the formation **2**.

By so maintaining the combustion zone **36** in the lower portion **25** of the formation **2**, the formation **2** can be more efficiently heated over the areal extent of the reservoir with a decrease in the volume of inplace hydrocarbons utilized for fueling the combustion zone **36** and a retarding of channels forming upwardly within the formation **2**.

As the formation 2 increases in temperature, the viscosity of the inplace hydrocarbons in lowered and the hydrocarbons begin to flow downwardly and enter the casing 24 of the production well 6. The pressure within the production well 6 below the packer 34 is lowered and these fluids are produced through the tubing 28 and recovered at the surface 20.

Periodically the injection of oxygen-containing gases into the formation 2 is terminated thereby terminating the advancement of the combustion zone 36 through the formation 2. A slug of volatile hydrocarbon liquid is thereafter injected downwardly through the tubing 18 of the injection well 4, through the lower perforations 10 and into contact with the combustion zone 36. The injection well is thereafter closed in. Contact of the volatile hydrocarbon liquid slug with the high temperatures of the formation 2 causes the volatile slug to vaporize, move upwardly through the formation 2 to further heat the upper portions 32 of the formation and dilute and lower the viscosity of the inplace hydrocarbons. It is therefore preferred that the injected liquid hydrocarbon slugs have a lower viscosity and a higher volatility than the inplace hydrocarbons when measured at the same temperature and pressure. Diesel oil is an example of an excellent volatile hydrocarbon liquid slug to be utilized with this invention.

After the temperature within the burned over zone has cooled to a temperature of about 300° F or below, the combustion zone 36 is again moved through the formation 2 by injecting oxidant as described above. If injection of oxidant is terminated an excessive length of time during which the area of the combustion zone 36 cools to a temperature below 180° F, it may be difficult to reinitiate in situ combustion within the formation 2. The amount of volatile liquid injected, the length of time of each in situ heating period, and the length of time during which the injection well is closed in are dependent upon the formation characteristics and the type of liquid utilized for the hydrocarbon slug. Optimum cycle periods and hydrocarbon slug types for a particular formation may be determined, however, by analysis and pilot laboratory tests run on core samples of the formation on which the recovery method of this invention is to be utilized.

In order to control the pressure within the formation 2, more efficient recovery of the inplace hydrocarbons and to prevent the need for extremely high horsepower to inject the oxidant and liquid slugs, it is preferred that the gases that accumulate in the upper portion 32 of the formation be produced to the surface 20 through the upper perforations 27 of the production well 6. The production of gases through the upper perforations 27 can be intermittently or continuously produced dependent upon the pressure desired to be maintained within said upper portion 32 of the formation 2. To further aid the refluxing of liquid hydrocarbons in permeable tar sands, noncondensable gases can be produced from the upper portion of the formation so that the condensable vapors can flow upwardly to be condensed and heat the tar sand. During this period of heat transfer upwardly and gravity drainage of oil into the heated zone, oil will be produced from the production wells. Another method to encourage heat transfer upwardly is to operate the reservoir at an elevated pressure to increase the rate of heat movement upwardly by natural condition.

By the thermal recovery method of this invention, the formation is more efficiently heated, channeling of the combustion zone is prevented by maintaining the oxidant supply in the lower portion of the formation, the heat of the combustion zone is intermittently transported more efficiently to other portions of the formation by the injected liquid slug, and heavy, viscous inplace hydrocarbons are diluted and their viscosity is lowered by the injected hydrocarbons.

Other modifications and alterations of this invention will become apparent to those skilled in the art from the foregoing discussion and accompanying drawing, and it should be understood that this invention is not to be unduly limited thereto.

We claim:

1. A method for recovering hydrocarbons from a subterranean formation penetrated by an injection well and a remotely located production well, comprising:
   a. establishing in situ combustion in only the lower portion of the hydrocarbon-containing formation;
   b. heating the formation by advancing the combustion zone through the formation;
   c. producing the production well;
   d. periodically terminating in situ combustion;
   e. injecting a volatile hydrocarbon liquid downwardly through the injection well and into the lower portion of the formation while at a temperature sufficient for volatilizing said liquid;
   f. closing in the injection well until the temperature within the burned over portion of said formation is below about 300° F; and
   g. thereafter repeating steps (*a*) through (*f*) at least once.

2. The method, as set forth in claim 1, wherein internal combustion is established adjacent the production well and the formation is heated by countercurrent in situ combustion.

3. The method, as set forth in claim 1, wherein, during combustion air is injected into the lower portion of the formation and an inert gas is injected into the upper portion of the formation.

4. The method, as set forth in claim 1, including lowering the pressure within the upper portion of the formation by producing gases therefrom through the production well.

5. The method, as set forth in claim 1, wherein the injected hydrocarbon liquid has a lower viscosity and a higher volatility than the liquid hydrocarbons within the formation.

6. The method, as set forth in claim 1, wherein the injected hydrocarbon liquid is diesel oil.