METHOD FOR PRODUCING SHALE OIL FROM AN OIL SHALE FORMATION

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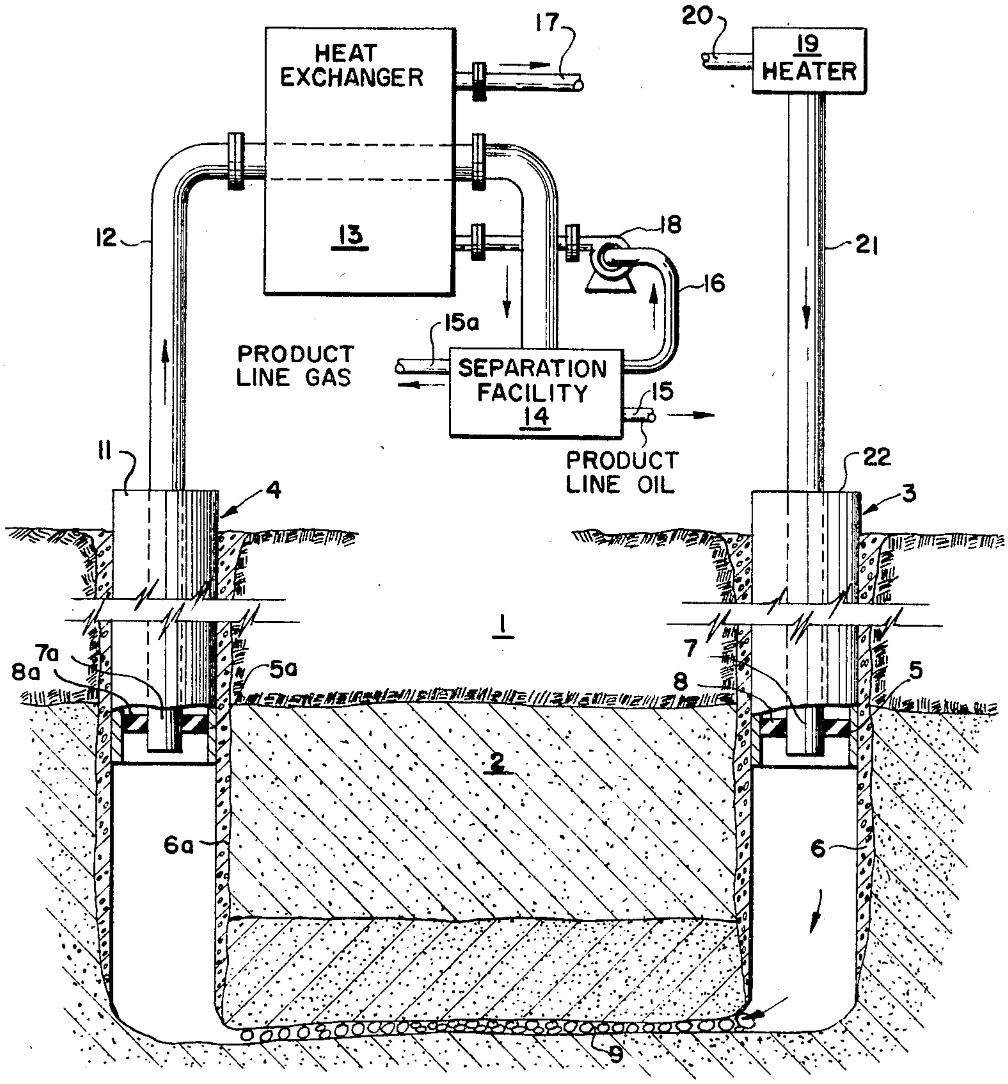

FIG. 1

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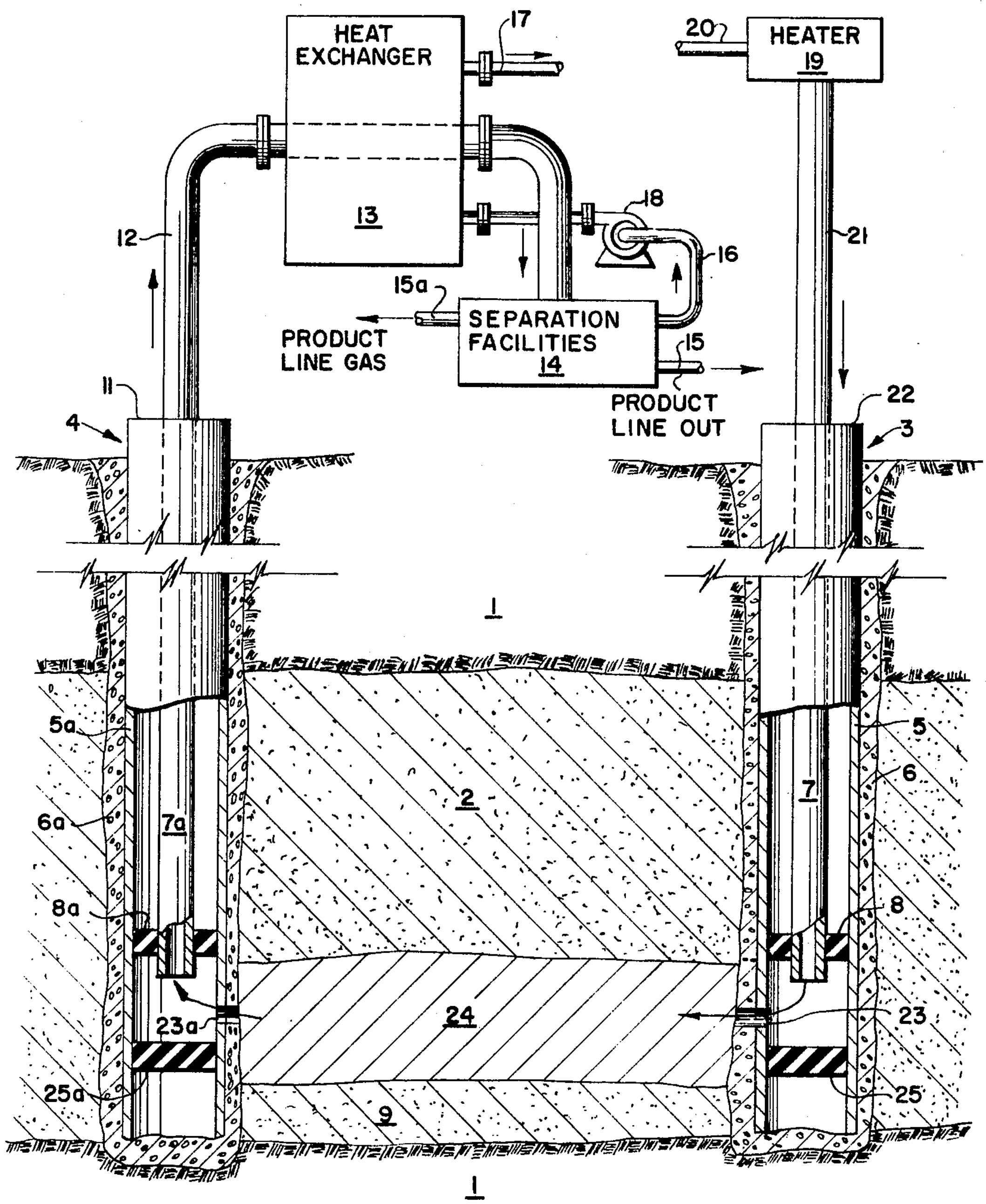

FIG. 2

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3,513,914
METHOD FOR PRODUCING SHALE OIL FROM AN OIL SHALE FORMATION

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ABSTRACT OF THE DISCLOSURE

Shale oil is produced from a subterranean oil shale formation by extending at least a pair of well boreholes into the formation only to a depth corresponding with the oil shale formation. A generally horizontal fracture is formed in the oil shale formation extending between the boreholes so that a fluid having a gaseous component therein may be circulated from one borehole through the fracture and out the other borehole while maintaining a pressure on the fluid sufficient to maintain a permeable channel through which fluid can flow. The permeability of the channel is maintained by lifting the weight of the earth overburden above the channel and permitting expansion of the solid mineral residue left after retorting the kerogen and removing the products from the oil shale formation. The gaseous component of the circulating fluid is heated to a temperature sufficient to retort and mobilize any organic components in the oil shale formation. The depths of the boreholes through which the heated circulated fluid is flowing are adjusted to correspond with the uppermost depth along which the fluid is circulating through the permeable channel.

BACKGROUND OF THE INVENTION

Field of the invention

The invention relates to a method for recovering shale oil from an oil shale formation. More particularly, it relates to a method of recovering shale oil from an oil shale formation by in-situ retorting.

Description of the prior art

Substantial petroleum deposits exist in solid or semi-solid form and these deposits, the so-called oil shale deposits, are the greatest oil reserves in the United States. These deposits were formed apparently from fresh water lakes in which organic matter, mostly of algal origin, collected with finely divided silt at the bottom of fresh water lakes. This organic matter subsequently dried, became compacted and was transformed into a laminated, impermeable organic-bearing mineral matrix known today as oil shale.

The existence of the petroleum in such a semi-solid form is not conducive to economic recovery by present day techniques but, because of the extensiveness of these oil shale deposits, they provide more than an adequate incentive to develop means of recovering the oil therefrom. For example, the Green River formation, located midway between Denver and Salt Lake City, extends over some 16,500 square miles, averaging 15 or more gallons of shale oil per ton. This is probably the world's single largest known hydrocarbon deposit with estimated reserves of over 150,000,000,000 barrels.

Presently, there are two broad approaches to the recovery of shale oil from the organic-inorganic matrix known as oil shale. One is the retorting of mined shale and the other is in situ treatment of the shale. Most

successful today of the two general types of processes is the treatment of mined shale by retort processes. The difficulty with such a proces is that a 50,000 barrel per day plant requires that 84,000 tons of raw, good grade, shale be processed through the plant per day and that 71,000 tons of inorganic residue be disposed of daily. Thus, the materials handling problems in such a process is enormous.

Because the organic matter in oil shale exists largely as an insoluble residue, often referred to as kerogen, having a molecular weight of 3000 plus, it is difficult to separate the organic matter from the inorganic matter without some modification of the kerogen. Heat converts it into a liquid or vapor form. This is the reason that retort processes involving mining the oil shale, transporting the shale to a suitable processing point, crushing and grinding the shale to a particle size permitting effective heat treatment and thereafter heating the resulting particles sufficiently to effect destructive distillation of the kerogen are not today economical.

Even though the potential recovery of shale oil may be as high as 50 to 75 gallons per ton, material handling problems have caused industry to look for other methods of recovering the oil products from oil shales. This has led to the second broad approach to the recovery of organic matter which involves attempts to heat the oil shales in situ to recover the useful organic matter. These latter techniques are much akin to the retort processes and, in fact, many use in situ retort processes either burning the organic matter in the shale or providing fuel within the formation to develop sufficient heat to cause destructive distillation thereby converting it to either recoverable liquid or vapor products.

While the in situ combustion processes eliminate the costly operations of mining, transportation and processing of the raw oil shale, the virgin oil shale is very strong and impermeable in its natural occurring state which adds other problems. It is difficult to establish in situ combustion and to maintain it once it has been initiated. Another problem faced with in situ oil shale combustions when this art is used is that the produced gases are highly contaminated with nitrogen which may reduce their fuel value almost to nothing. Another difficulty with in situ combustions is the presence of both magnesium carbonate and calcium carbonate which begin to calcine from about 1100° to about 1500° F. via an endothermic reaction which is also undesirable.

Since both of the general techniques discussed above have their own unique problems, other approaches to the recovery of organic matter from oil shale have been sought. One such technique is disclosed in my previous Pat. No. 3,358,756. In this patent, oil shale is recovered from an oil shale formation by penetrating the formation with at least one injection well and at least one production well. The formation is fractured between the wells and a non-oxidizing heated vapor is injected through the injection well. Effluents are recovered from the production well which effluents include organic materials formed from the solid to semi-solid organic matter in the formation by a thermal cracking action. In this patent, propped fractures and gas injection pressures lower than the overburden pressure are used to recover oil shale from the oil shale formation. However, thermal expansion effects resulting from this process may plug or materially reduce the permeability of the propped fraction. In addition, the permeability of the mineral matrix is very low when compressed by overburden pressure, even after removal of the organic materials. Thus, most of the hot vapors injected flow through the fractures and heating of the undepleted kerogen-bearing oil shale occurs principally by heat conduction away from the original fractures. This may require prolonged periods of time, as much as 5 years being required to conduct retorting heat to 25 feet away from the fractures.

Other in-situ combustion processes utilize caverns into which oil shale is caved or spalled such as those described in Pat. Nos. 3,223,158; 3,233,668; and 3,241,611. A copending application to Bruist, Ser. No. 543,698, filed Apr. 19, 1966 relates to such an in-situ combustion oil shale retorting process. In this application, injection and production wells are drilled directionally so that they intersect within the oil shale formation. The zone of near intersection is fractured and solids are removed in order to form a cavern containing rubbled oil shale. Portions of the rubble are burned in order to retort other portions and the roof of the cavern is allowed to spall into or is caved into the cavern in order to bring additional portions of oil shale into contact with the hot gas. Processes of this type, therefore, involve the removal of huge quantities of solids thereby raising enormous materials handling problems.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an improved method for retorting an oil shale formation in situ.

It is a further object of this invention to provide a method for retorting an oil shale formation in situ by circulating heated fluid from one well to another through a permeable channel without plugging or reducing the permeability of the channel.

These objects are carried out by extending at least a pair of well boreholes into a subterranean oil shale formation only to a depth corresponding with the oil shale formation. A generally horizontal fracture is formed in the oil shale formation extending between the boreholes and a fluid having a gaseous component therein is circulated from one borehole through the fracture and out the other borehole while maintaining a pressure on the fluid sufficient to maintain a permeable channel through which fluid can flow. The channel is enlarged and its permeability is maintained by lifting the weight of the earth overburden above the channel and permitting the mineral matrix to expand as heat is applied and kerogen removed. The gaseous component of circulating fluid is heated to a temperature sufficient to mobilize any organic components in the oil shale formation and the depths of the boreholes through which the heated circulated fluid is flowing are adjusted to correspond with the uppermost depth along which the fluid is circulating through the permeable channel.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a vertical sectional view of an oil shale formation in accordance with the teachings of this invention; and

FIG. 2 is a vertical sectional view of an oil shale formation in accordance with a further application of the teachings of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1 of the drawing, a subterranean earth formation **1** is shown composed of a plurality of strata including a reservoir formation **2** composed principally of oil shale. In practicing this invention, at least one injection well **3** and at least one production well **4** are drilled through the earth formation **1** to penetrate the shale formation **2**. The illustrated construction of both the injection well **3** and the production well **4** is quite similar each having a casing (such as casing **5** and **5***a*, respectively) positioned in the borehole and sealed with a sealant (such as sealant **6** and **6***a*) to maintain its location therein. Wells **3** and **4**, respectively, are preferably cased only to the depth of the earth formation overburden **1**. The use of uncased well boreholes is feasible because of the impermeability of native oil shale.

Alternatively, the well boreholes **3** and **4** may be cased and perforated along part or all of the shale interval as illustrated in FIG. 2. In FIG. 2, like numerals refer to like parts of FIG. 1. Where casings are perforated through only part of the shale interval, as in FIG. 2, the hot wells must be re-entered in order to provide perforations at new levels at which fluids will flow through the shale. Well boreholes **3** and **4**, however, are preferably cemented along the oil shale interval so as to prevent the escape of vapors from well boreholes **3** and **4** into formation **2**. The invention will be described with respect to the uncased wells of FIG. 1; the principles applied to the wells of FIG. 1 are also applicable to the wells of FIG. 2 with the exception of re-entering the wells of FIG. 2 as the permeable channel migrates upwardly which will be discussed further hereinbelow.

Preferably, inside each casing string **5** and **5***a* there is an insulated tubing string (such as tubing string **7** and **7***a*, respectively) which is positioned in the casing string to leave an insulating annulus therebetween which is sealed near the lower end of the tubing string by packer **8** and **8***a*, respectively (FIG. 1).

Since, in all probability, the shale formation **2** will be impermeable, it will be necessary to fracture between the input well **3** and the production well **4**. A generally horizontal fracture **9** is preferably established by the use of conventional hydraulic fracturing fluids.

In operation, a fluid, having a gaseous component therein, is circulated through the oil shale formation **2** by pumping it in through the tubing string **7** of injection well **3**, through the generally horizontal fracture and out of the tubing string **7***a* of production well **4**.

Simultaneously, sufficient pressure is maintained on the circulating fluid to maintain a permeable depleted zone or channel **24** through which the circulating fluid can flow by lifting the weight of the overburden and permitting expansion of the solid mineral matrix of the oil shale within formation **2**.

It is preferred, but not essential, that the circulating fluid having a gaseous component therein be a nonoxidizing gas such as an organic material which, while not miscible with the insoluble kerogen, is miscible with the cracked products obtained by circulating the hot fluid through oil shale formation **2**. Suitable hydrocarbons are discussed in my Pat. No. 3,358,756 and are incorporated herein by reference.

It is desired that the circulating fluid be continuously recycled through the formation to effect the recovery of the organic matter therein, the discussion of the aboveground equipment will begin with the effluents of production well **4** and terminate with the injection of the circulating fluid through injection well **3**. At the wellhead **11** of casing string **5***a* of production well **4**, the vaporous effluents are recovered through the insulated tubing string **7***a*, pass through line **12** and go directly to heat exchanger **13** and thence to a separating facility **14** in which the cracked products from the formation are separated from the heated circulating fluid which was injected through the injection well **3** to recover these products. Depending on the particular fluid mixture used, the separation facility **14** may consist of simple conventional equipment for separating gases and liquids by gravity or may require somewhat elaborate distillation and condensation equipment. The oil and gas products are recovered through product recovery lines **15** and **15***a* and the heat carrying fluid, which was injected in vapor form, is removed from the separating facility **14** and pumped by pump or compressor **18** through line **16** and directly into heat exchanger **13** through line **17**. From line **17**, the fluid passes directly to a suitable heater **19** via line **20** wherein the fluid is raised to an oil shale-retorting temperature, such as a temperature in excess of 700° F.

From heater **19**, the heated fluid is routed via insulated pipe **21** to the wellhead **22** of injection well **3**. There the heated fluid travels down the insulated tubing string 7 of injection well 3 and proceeds via tubing string 7 through permeable channel 24. From channel 24, the heated fluid transmits its heat by conduction and/or convection to the portions of oil shale formation 2 adjacent channel 24. As the vapors of the heated fluid flow through the channel 24 to the production well 4, some of the organic matter in the oil shale formation 2 is thermally cracked to lower boiling points which are much less viscous. Once the cracked products from the organic matter in oil shale formation 2 are reduced to low viscosity products and/or vaporized, they are forced out of their original position by expanding vapor pressure and swept along with the heated fluid to the production well 4 from whence they are recovered via tubing string 7*a*. Suitable temperature and pressure control means (not shown) may be coupled to heater 19 and compressor 18, respectively.

In my aforementioned patent, it was pointed out that as the area adjacent to the initial fracture becomes depleted of organic matter, it becomes somewhat permeable to the hot hydrocarbon vapors allowing them to contact more virgin shale. If, as in my aforementioned patent, the process is carried out at pressures substantially below overburden pressure, permeabilities on the order of 1 to 30 millidarcies result. This is very low and most of the hot vapors must continue to flow through the fracture so that heating of the undepleted kerogen-bearing oil shale occurs principally by conduction away from the original fracture. This is relatively a very slow process, as much as five years being required to conduct retorting heat to a distance of 25 feet away from the fracture. In addition, it is obvious that maintenance of fracture permeability is essential, both to permit injection and circulation of the heating fluid and withdrawal of the cracked products. Maintenance of fracture receptivity may be something of a problem because of the tendency of the heavy residual cracked ends of the kerogen retorting products to congeal in cooler portions of the fracture and plug them off.

However, by carrying out the process described in my aforementioned patent in accordance with the teachings of this invention, at pressures equal to or higher than overburden, the permeability of the depleted oil shale is several hundred times greater than when low pressures are used, permitting free flow of injected hot vapors to carry heat close to the virgin undepleted shale and sweep the products into the producing well bore. This permits much faster heating of the oil shale and, once the process has well begun, eliminates dependence on fracture receptivity because depleted zone 24 now offers lesser resistance to flow than initial fracture 9 even when fracture 9 is in perfect condition. From FIG. 1, it is obvious that as depletion proceeds, the channel of permeability zone 24 migrates upwardly through the oil shale formation 2 causing shale oil to be produced substantially from the entire interval.

The depths of the boreholes 3 and 4 through which fluid is circulating are adjusted to correspond with the uppermost depth along which fluid is circulating through the permeable channel 24 (FIG. 2) within the oil shale formation 2. This adjustment is automatic in the case of the wells of FIG. 1. In the wells of FIG. 2, the wells must be re-entered so as to raise the tubing strings 7 and 7*a* and the packers 8 and 8*a* as the permeable channel 24 migrates upwardly to the upper packers. Thus, the arrangement of FIG. 2 includes packers 25 and 25*a* associated with wells 3 and 4 respectively, and suitable perforations 23 and 23*a* for carrying out the operations discussed hereinabove.

The following is an explanation of why greater permeability results at higher pressures. When oil shale is retorted in the absence of restraining mechanical forces, it has been found that the mineral matrix swells and exfoliates and, after completion of retorting, the permeability is found to be 2000 to 3000 millidarcies. If

retorted under mechanical restraint, however, as when a core is mounted in a metal tube before retorting or when a block of shale is pressed between two metal plates during retorting, it is found that the permeability after retorting is only 1 to 30 millidarcies. The mineral matrix obviously acts much like a sponge, expanding if permitted to do so, and offering high permeability to permit fluid flow in its expanded state, but readily compressed by mechanical forces and then exhibiting low permeabilities and high restriction to fluid flow.

When underground retorting is carried out at low pressures, the weight of the overburden must be supported by depleted zone 24, which is then compressed between the overburden and underlying rocks just as a block of shale rigidly held between two metal plates. If, however, in accordance with the teaching of this invention, a high fluid pressure is used, this pressure acting between the underlying rocks and the virgin impermeable undepleted oil shale supports the overburden with hydraulic pressure, freeing zone 24 of mechanical constraint and permitting free expansion and exfoliation. The overburden must slowly be lifted by the hydraulic pressure as this sponge-like expansion occurs. There is no tendency for the high hydraulic pressure to inhibit the expansion and exfoliation of the depleted zone 24 because this pressure is uniformly distributed throughout the porous and permeable zone 24, giving completely balanced and neutral forces on all individual grains in the mineral matrix.

Although the present invention is directed towards underground retorting with a hot nonoxidizing vapor used as the heat carrying medium, the principle of using high process pressures to induce expansion and exfoliation would also be of value in in situ combustion processes where air or oxygen is injected underground to burn a portion of the kerogen and supply retorting heat from this combustion.

Though we have discussed the invention relative to the use of two spaced wells, one of which is the injection well and one of which is the production well, it should be appreciated that it would be possible to carry out the instant process in a single well with dual insulated tubing strings and through a vertical fracture.

Further, it should be appreciated that the facilities located above the ground would all involve appropriate insulation in order to conserve thermal energy and the use of appropriate heat exchangers in order to recover the maximum amount of thermal energy from the effluents from the production well. In this way, the efficiency of the process can be improved and it can be operated on a commercial scale.

I claim as my invention:

1. In a method for recovering shale oil from a subterranean oil shale formation comprising the steps of:

extending at least a pair of well boreholes into said oil shale formation only to a depth corresponding with said oil shale formation;

forming a generally horizontal fracture within said oil shale formation extending between said pair of boreholes;

circulating a fluid having a gaseous component therein through said oil shale formation by pumping said fluid from one of said boreholes through said fracture and out the other of said boreholes while maintaining a pressure on the fluid sufficient to maintain a permeable channel through which fluid can flow;

maintaining the permeability of said channel by lifting the weight of the earth overburden above said channel and permitting expansion of the solid components of the oil shale formation;

heating said gaseous component of said circulating fluid to a temperature sufficient to mobilize organic components in said oil shale formation; and

adjusting the depths of said boreholes through which heated circulating fluid is flowing to correspond with the uppermost depth along which fluid is circulating through said permeable channel within the oil shale formation.

2. The method of claim 1 including the step of recovering shale oil from the fluid circulating out of the other said boreholes.

3. The method of claim 1 wherein the step of circulating a fluid having a gaseous component therein includes the step of circulating a nonoxidizing gas.

4. The method of claim 1 wherein the step of adjusting the depths of said boreholes includes the step of automatically adjusting the depths of said boreholes as said permeable channel migrates upwardly through the oil shale formation.

5. The method of claim 1 wherein the step of heating said gaseous component of said circulating fluid includes heating said fluid prior to circulating said fluid through said oil shale formation.

6. The method of claim 1 wherein the step of heating said gaseous component of said circulation fluid includes heating said fluid in situ within said oil shale formation.

7. The method of claim 1 wherein the step of maintaining the permeability of said channel by lifting the weight of the overburden includes the step of lifting said overburden by hydraulic pressure.

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U.S. Cl. X.R.

166—259, 272