IN SITU THERMAL RECOVERY OF OIL FROM AN OIL SHALE
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FIG. 1

FIG. 2

FIG. 3

PYROLYSIS DUE TO BURNING

BY

ATTORNEYS
ABSTRACT OF THE DISCLOSURE

An oil shale formation penetrated by an injection well and a production well is fractured from one well to the other. A portion of the fractured formation extending part of the way between the wells is subjected to superheated steam, and oil is recovered through the production well. The steamed portion of the formation is then subjected to in situ combustion to produce additional oil in the production well. The steaming and combustion of steamed portions are alternately continued until the combustion front reaches the production well.

This invention relates to a process for producing oil from an oil shale. Large deposits of oil in the form of oil shale are found in various sections of the United States and, particularly, in Colorado and surrounding states. Various methods of recovery of oil from these shale deposits have been proposed and the principal difficulty with these methods is the high cost which renders the recovered oil too expensive to compete with petroleum crudes recovered by more conventional methods. The in situ retorting of oil shale to recover the oil contained therein is made difficult because of the nonpermeable nature of the oil shale and the difficulty of applying heat thereto without extensive mining or drilling operations. The mining and removal of the oil shale for retorting of the shale in furnaces outside the formation is commercially uneconomical in most cases.

This invention is concerned with a process for the thermal recovery of oil from shale in situ which avoids mining and removal of the oil shale for retorting. Accordingly, it is an object of the invention to provide a process for the thermal in situ production of oil from an impermeable oil shale. Another object is to provide a process for the production of oil from oil shale by in situ heating which avoids mining of the shale and retorting of same above ground. Other objects of the invention will become apparent to one skilled in the art upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises fracturing an oil shale by conventional fracturing techniques between an injection well and a production well penetrating the shale stratum, preferably, at several different levels therein and holding the fractures (open) injecting superheated steam into the fractures of the stratum thru the injection well so as to heat the stratum and establish a thermal front therein; after a substantial section of the stratum has been heated and oil driven therefrom thru the fractures into the production well, terminating steam injection and injecting combustion-supporting, O2-containing gas into the stratum (fractures) thru the injection well so as to initiate a direct drive in situ combustion operation thru the section of stratum heated by the steam; and, after the combustion front has been driven thru a substantial portion of the steam-heated section of stratum, terminating injection of combustion-supporting gas and repeating the steam injection and gas injection steps sequentially, the produced oil and gas from the steam and combustion steps being recovered thru the production well.

The fractures are held open to gas flow during the injection steps either by injecting a propping agent into the fractures during or after the fracturing operation or by maintaining sufficient gas pressure in the stratum during the injection steps to hold the fractures open.

In order to efficiently heat the stratum during steam injection, it is preferred to operate with steam at a temperature of at least 800°F, and more desirably, 1000°F. The steam injection phase or step of the operation heats and fluidizes the kerogen or solid oil in the oil shale, rendering the same readily flowable as liquid and vapor. Steam injection is continued for a period ranging from several weeks to several months to as to heat a substantial section of the oil shale extending in the range of 5 to 25 feet or more into the stratum from the injection well and the oil thermally produced from the shale is driven thru the fractures into the production well from which it is readily produced by pumping or in other conventional manner.

Air is the preferred combustion-supporting gas because of its ready availability and low cost but oxygen-enriched air may be utilized. Upon contacting the hot oil shale with air, combustion is initiated which adds additional large quantities of heat to the stratum, thereby thermally producing additional shale oil and expanding the pyrolysis zone. The combustion feeds on residual coke and liquid oil in the pyrolysis zone. When the combustion zone has been driven thru a substantial portion of the pyrolysis zone formed during the steam injection step, air injection is terminated and steam injection is again resumed. After another substantial steam injection period, this step is terminated and air is again injected thru the injection well into the expanded pyrolysis zone for further combustion of residual coke and hydrocarbon material therein. The alternate movement of the pyrolysis zone by steam and combustion greatly improves the recovery of shale oil compared to either method alone and more rapidly opens up the entire shale stratum to gas flow, rendering the stratum more permeable.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is an elevation thru a stratum penetrated by an injection well and a production well, illustrating the fracturing and propping phase of the operation; FIGURE 2 is a similar view illustrating the conditions in the stratum after a substantial steam injection period; and FIGURE 3 is a similar view illustrating the combustion phase of the operation.

Referring to FIGURE 1, an oil stratum is penetrated by an injection well 12 and a production well 14. Tubing string 16 in injection well 12 extends to a lower section of stratum 10 and forms an annulus 18 with the wall of the well for casing 20. A packer 22 packs off the annulus at the approximate top level of the shale stratum. A similar arrangement in well 14 includes a tubing 24, a casing 26, and a packer 28. Fracturing fluid is applied thru tubing 16 and tubing 24, if desired, so as to build up sufficient fracturing pressure to produce fractures at selected levels, such as 30, 32, 34, and 36. If the fractures are to be propped, the proppant described above is mixed with the fracturing fluid. After the fractures have been opened, sufficient gas pressure is built up to effect the fracturing, and steam is injected thru the steam injection string 36 into the formation thru the propped fractures. The steam moves thru the formation at a speed determined by the pressure of the steam, the temperature of the steam, and the permeability of the formation. As the steam reaches the production well 14, the produced oil and gas move thru the formation back to the production well 14 and are removed from the well 14 thru tubing 24 and tubing 16. When sufficient oil and gas have been recovered, the steam injection is stopped and the fractures are propped open with air or with a propellant gas passing thru the propped fractures from the steam injection string 36 to the production well 14. The fractures are held open by the propellant gas until the oil is recovered from the fractures. When the production well reaches the bottom of the oil producing section, the steam injection is again started and the foregoing process is repeated.

Casing strings 20 and 26 may be cemented in at the top of the stratum or they may extend to the bottom, in which case they are perforated at selected levels there-in coinciding with the fracturing levels (and at intermediate levels, if desired).
Referring to FIGURE 2, a steam generator 38 provides steam from a source of water not shown and the steam passes thru line 40 to a steam superheater 42 for heating to the desired temperature. The superheated steam is injected thru line 44 into tubing 16 from which it passes to the well below packer 22 and enters fractures 30, 32, 34, and 36, which are either held open by propping material or by steam injection pressure by regulating the back pressure on well 14. After an extended steam injection period, a saturated steam zone exists between dotted line 46 and 48 with a steam plus condensate (H₂O) occupying a substantial zone between lines 48 and 50. The pyrolysis zone extends from the wall of well 12 to line 50 at the end of a substantial steaming period. The zone between the wellbore and line 46 contains superheated steam. The steam injection phase of the operation produces fluid shale oil thru the fractures into well 14 and recovery is made thru tubing 24.

Referring to FIGURE 3, at the end of the steam injection phase of the operation, steam injection is terminated and air is injected thru line 52 under the impetus of a compressor, not shown, into tubing string 16 from which it invades the stratum via the wellbore and the several fractures in the stratum. Upon contacting the hot stratum containing the superheated steam adjacent well 12, the residual coke and/or shale oil is ignited to establish a combustion front which moves slowly away from the injection well as air injection is continued. A combustion catalyst may be utilized, if desired.

The combustion phase of the operation not only consumes a portion of the coke and oil as fuel but also fluidizes additional kerogen and semi-solid hydrocarbon material to drive additional shale oil from the stratum, and it also imparts additional heat to the stratum and expands the pyrolysis zone as illustrated at line 54. During the combustion step, the additional produced oil is recovered thru tubing string 24 as before. The combustion step and the expansion of the pyrolysis zone opens up additional stratum for passage of gas (steam, air, and/or combustion gases), materially increasing the permeability of the stratum adjacent the fractures. By repeating the steam injection and combustion steps, the stratum is opened up completely between the fractures so that substantially all of the oil in the shale is produced and production is continued until the pyrolysis zone is extended completely to the production well and until further injection of steam and air fails to result in economic production of oil.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

We claim:
1. A process for producing oil from an oil shale stratum penetrated by an injection well and a production well, which comprises the steps of:

(a) fracturing said stratum from one well to the other and holding resulting fracture(s) open during the following steps:
(b) injecting superheated steam at a temperature of at least 800°F thru said injection well into said stratum thru said fracture(s) so as to heat a substantial section of said stratum extending from said injection well part of the distance to said production well and produce oil therefrom thru said fracture(s) and thru said production well;
(c) terminating steam injection of step (b) and injecting a combustion-supporting, O₂-containing gas into said stratum thru said injection well so as to initiate and maintain a direct drive in situ combustion front thru the hot residual hydrocarbon and coke in the section of stratum heated in step (b);
(d) recovering thru said production well oil produced in step (c);
(e) when the combustion front of step (c) has been driven thru a substantial portion of the section of stratum heated in step (b) terminating the injection of said combustion-supporting, O₂-containing gas; and
(f) repeating steps (b), (c), (d) and (e) a plurality of times to alternately establish a new steam heated portion of said stratum extending an additional portion of the distance between said injection well and production well and then establish and maintain an in situ combustion front in said new steam heated portion of said stratum until the in situ combustion front has been driven thru a substantial portion of said new steam heated portion, until the in situ combustion front reaches completely to said production well.

2. The process of claim 1 wherein said stratum is fractured at several different levels in step (a).

3. The process of claim 1 wherein said particular propping agent is injected into the fracture(s) to hold same open.

4. The process of claim 1 wherein said fractures are held open during injection in steps (b) and (c) by pressure of the injected gas.

5. The process of claim 1 wherein said gas is air.

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STEPHEN J. NOVOSAD, Primary Examiner.