METHOD OF PRODUCING SHALE OIL FROM A SUBTERRANEAN OIL SHALE FORMATION

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3,501,201

METHOD OF PRODUCING SHALE OIL FROM A SUBTERRANEAN OIL SHALE FORMATION

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Filed Oct. 30, 1968, Ser. No. 771,961

Int. Cl. E21b 43/24, 43/26, 43/28

U.S. Cl. 299—4

13 Claims

ABSTRACT OF THE DISCLOSURE

A method of recovering shale oil from a normally impermeable subterranean oil shale formation by extending at least a pair of well boresholes into at least one layer of water-soluble minerals disposed in the formation and forming generally vertical fractures extending along generally parallel paths from each of the boresholes. Hot fluid is injected through at least one of the well boresholes until flow into at least one of the fractures therein is thermally closed by the swelling-shut of the walls of the fracture. Fluid in at least one borehole in which at least one fracture has been thermally closed is pressurized until at least one new fracture is formed and the steps of injecting hot fluid and the pressurizing of fluid are repeated at successively higher temperatures and pressures until the resultant fractures form a channel interconnecting the well boresholes through which fluid can flow from one well borehole to another. The walls of the fractures interconnecting the boreholes are leached at a controlled temperature until channels provided between the well boresholes are capable of remaining open while hot fluid is circulated between the boresholes.


BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to a method for recovering shale oil from a normally impermeable oil shale formation normally subject to vertical fracturing and having at least one layer of water-soluble minerals disposed therein.

Description of the prior art

It is known that it is extremely difficult to recover liquefiable components from deposits of various subterranean impermeable formations such as oil shale, coral beds, deposits of cinnabar, etc. under conditions in which the deposits are normally present in these formations. Various proposals have been made, such as described in a U.S. Patent No. 3,284,281, to recover oil from oil shale. Herein oil shale is produced from the Green River formation through fractures interconnecting wells. However, under the conditions described therein, the fractures tend to close as their walls become heated and thermally expanded and oil recovery is stopped. Under conditions described, it is generally necessary to resort to a repeating sequence of heating and expanding and refracturing operations until flow patterns are finally formed that will remain open while the desired components are being liquefied.

In certain situations, particularly at relatively shallow depths, a heating procedure can be utilized to cause the swelling tendencies of the earth formations to create horizontal stresses that exceed the vertical stresses. By such a procedure, pairs of wells can be interconnected by means of a horizontal fracture that can be kept open by hydraulically lifting or compressing the overlying earth formations. Such a procedure, in which the heating is accomplished by injecting a liquid while maintaining a specified rate of fluid flow and temperature increase, is described in a copending application to Matthews et al., Ser. No. 578,533, filed Sept. 12, 1966, now Patent No. 3,455,391.

However, normally, horizontal fractures cannot feasibly be formed by thermally increasing the horizontal stresses. Generally, heating oil shale formations causes the vertical stresses to increase at a rate comparable to that at which the horizontal stresses are increased and this prevents the formation of a horizontal fracture. Although communication between wells might be established by repetitively heating and fracturing at successively higher pressures and temperatures, as proposed in the aforementioned U.S. patent, this would result in excessively high operating costs and the production and maintenance of higher pressures and temperatures than are actually required.

When the regional tectonics are such that vertical fractures form and propagate along generally parallel paths when fluid is injected into adjacent wells at the normal subsurface temperature at pressures and rates sufficient to form and extend the fractures, the use of the successively higher pressures and temperatures is apt to form a succession of numerous differently oriented vertical fractures at pressures which do not become high enough to produce a horizontal fracture. The pressure necessary to form a horizontal fracture is generally about equal to or slightly less than one p.s.i. per foot of depth. When, for example, a vertical fracture opening into a first well has been extended for a significant distance and at least one vertical fracture has been opened and then thermally closed in a second well, the formation and extension of a subsequent fracture from the second well is apt to cause the fractures to intersect so that fluid can flow from one well to the other. However, if the fluid pumped through such intersecting fractures is heated, at or above the temperature at which the last fracture was formed, the walls of the fracture will swell and the flow path will close.

Recent geological investigations have disclosed the presence of substantial amounts of water-soluble minerals (such as alkali or a lens of halite and napholite) in certain sub-surface oil shale formations such as in the Green River formation in the Colorado area of the United States. Such minerals have been mined commercially in the past by solution-mining by pumping a liquid solvent, e.g., aqueous acidic solutions, into the vein or bed in which the mineral is found and returning the extracted solution preferably as a mineral-containing solution to the surface of the earth and extracting the minerals from the solution by any suitable means.

For example, it has recently been found that layers of nahcolite, each two to three feet deep, underlie a large portion of the Green River Ranch in the Green River Basin of Colorado. In addition to the value of nahcolite as a mineral, these layers provide a means of contacting a significant portion of the oil shale deposit.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a method of recovering shale oil from a normally impermeable oil shale formation by extending generally vertical fractures
between wells extending into water-soluble mineral layers posed in the formation. It is a further object of this invention to provide a method of interconnecting wells extending into normally impermeable oil shale formations by forming generally vertical fractures between such wells. It is a still further object of this invention to interconnect wells extending into oil shale formations by means generally vertical fractures which remain open so that fluid remains unrestricted between such wells. These objects are preferably attained by forming generally vertical fractures extending along generally parallel paths from at least a pair of well boreholes extending into normally impermeable subterranean oil shale formations. Hot fluid is injected through at least one of the well boreholes until flow from at least one of the fractures is thermally closed by the swelling-shut of the walls of the fracture. Fluid in at least one borehole in which at least one fracture has been thermally closed is repressurized until at least one new fracture is formed and the steps of injecting hot fluid and the pressurizing of fluid are repeated at progressively higher temperatures and pressures until the resultant fractures form a channel interconnecting the well boreholes, through which channel fluid can flow from one borehole to another. The walls of the fracture interconnecting the boreholes are leached at controlled temperature and produced channels are provided between the boreholes capable of remaining open while fluid is circulated between the boreholes. This is accomplished by injecting a leaching fluid into one of the boreholes opening into the well-interconnecting fracture channel and producing fluid from another of the boreholes opening into that fracture channel, with the fluid being injected at a temperature below that at which the last fracture was opened into the well borehole into which the circulating fluid is injected but above that at which the last fracture was thermally closed within the well borehole into which the circulating fluid is injected in order that most of the injected fluid is conveyed through the channels interconnecting the boreholes.

Thus, when such a flow path is opened between a pair of wells, the path may be kept open by lowering the temperature of the fluid pumped through the path to a temperature that is less than that at which the last fracture was thermally closed but greater than that at which the preceding fracture was thermally closed. In addition, if the effective permeability of the flow path between the well boreholes is then increased by circulating through it a fluid that removes solid components from the walls of the channels, the flow path is converted to one through which the flow of fluid from one well borehole to the other remains efficient at whatever temperature is subsequently imparted to the fluid.

The attainment of a significant increase in the effective permeability of such a flow path may be detected by an increase in the rate of flow in response to the injection pressure that was initially required to displace fluid from one well borehole to another. If the temperature of the circulating fluid is too high relative to the rate which permeability is being increased, this may be detected by a reduction in the flow rate. If the temperature is too low relative to the rate at which the permeability is being increased, this may be detected by a decrease in the rate of outflow from the production well borehole without a corresponding decrease in rate of inflow into the injection well borehole. Where the temperature is too low, a reduction in the rate of flow of the circulating fluid results in a decrease in the temperature of the fluid, which may result in a corresponding decrease in the effective permeability of the system.

BRIEF DESCRIPTION OF THE DRAWING

FIGURE 1 is a vertical sectional view of a subterranean oil shale formation in accordance with the teaching of my invention;

FIGURE 2 is a top plan diagrammatic view of a preferred arrangement of well boreholes in accordance with the teachings of my invention.

FIGURE 3 is a vertical sectional view of a well borehole extending into the oil shale formation of FIGURE 1;

FIGURES 4 through 6 are vertical sectional views of preferred arrangements for producing oil from the well borehole formation of FIGURES 2; and

FIGURE 7 is a vertical sectional view of an alternate method of treating the oil shale formation of FIGURES 4 through 6.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGURE 1, an oil shale formation 11 is shown having at least one bed or layer of water-soluble minerals such as nacohite layers 12 and 12 disposed therein. The distance D between such layers, for example, may be on the order of 300 feet or so. Such layers 12 and 13 may, again for example, be on the order of two to three feet thick and underly a large portion of oil shale formation 11.

Layers 12 and 13 may be utilized in order to form communication between at least a pair of well boreholes extending into a subterranean earth formation. For example, as illustrated in FIGURE 2, a pattern of five well boreholes, such as production well boreholes 14 through 17 and 18, may be drilled by means well known in the art into the oil shale formation 11 to points communicating with layers 12 and 13 (FIGURE 3). Injection well borehole 18 may be fractured hydraulically so as to develop a generally vertical fracture 19 (FIGURE 2).

Such fractures may be formed by any known technique such as by applying a fluid pressure above the breakdown pressure of oil shale formation 11. Injection well borehole 14 may then be hydraulically fractured so as to develop a generally vertical fracture 20 generally parallel to fracture 19. Hot fluid, such as hot water, steam, or hot gas is next injected down well borehole 14 causing the fracture 20 to close and a new generally vertical fracture to develop in some other direction, as for example, fracture 21. This procedure may be continued in well borehole 14 until a generally vertical fracture, such as fracture 22, is formed which communicates with the fracture 19 extending from the central injection well borehole 18 thus inter-connecting well boreholes 14 and 18. These steps are carried out at each well borehole 15, 16 and 17 until all the well boreholes develop generally vertical fractures communicating with the centrally located fracture 19 extending from well borehole 18, as for example, generally vertical fractures 23, 24 and 25, respectively.

Next, the water-soluble mineral layers 12 and 13 are partially dissolved or leached out successively at the four corners of the well borehole pattern of FIGURE 2 leaving substantially void spaces therein. This may be accomplished by lowering a flexible tubing 26 down tubing string 27 disposed in well borehole 14, for example, (FIGURE 3). Well borehole 14 may be cased as at casing 28 with casing cement 29 therein as is well known in the art. The water-soluble minerals in layer 12 are then dissolved by jet action from an aqueous leaching or solution-mining liquid. The aqueous liquid may comprise water and/or steam or aqueous solutions of acid or acid-forming materials and is circulated at pressure either above or below the overburden pressure. The circulating aqueous liquid dissolves the water-soluble minerals in layer 12 and mineral by-products thereof are recovered from the fluid flowing out of well borehole 14 by conventional evaporation and/or precipitation procedures. Layer 13 may be treated in the same manner with well boreholes 15, 16 and 17 also treated accordingly.

As an alternative to tubing 26, the vertical fracture 20 already developed in well borehole 14 may be used to inject a water-soluble mineral fluid into layers 12 and 13.
The leached void spaces or zones (indicated by the outlined areas of FIGURE 2) of layers 12 and 13 tend to be relatively narrow channels, however, following more or less the line of the fractures. These channels are widened by a continuation of the leaching action, and the rate of the widening can be enhanced by an intermittent flow and/or alternately reversed-direction flow of the leaching fluid.

Hot fluid, such as hot water, steam or hot gas, is next injected down the corner well boreholes 14 through 17 to flow through fractures 22 through 25 and out of injection well borehole 18. Alternatively, such fluid may be either injected down well borehole 18 to flow through the fractures and out of the corner well boreholes or a combination of both procedures.

Such hot fluid flows through the interconnecting fractures and void spaces, causing the oil shale contacted therein to be heated and to expand into the void spaces developed in the water-soluble mineral layers 12 and 13. If the fractures tend to close due to thermal expansion, they may be partially leached out with hot solvent, acid or other reacting fluid which removes both organic matter and mineral content. In this manner, the channels formed by the fractures and void spaces remain permeable long enough to permit significant heating and thermal expansion of the oil shale into the void spaces formed by the leaching layers 12 and 13. In addition, spalling may take place into the void spaces due to expansion of the oil shale near the free spaces of the void spaces. The thermal expansion of the oil shale permits the development of many horizontal fissures 29 (FIGURE 4) along the bedding planes of oil shale formation 11. As can be seen in FIGURE 4, hot fluid is injected down tubing string 27 disposed in well borehole 14 and flows through permeations therein through the vertical fracture 22 formed between well borehole 14 and 18, through perforations 31 and out of well borehole 18. All the well boreholes may include conventional equipment for injecting, heating, and separating such fluids as is well known in the art. Well borehole 18 may also be cased at casing 32, with casing 32 cemented therein as is well known in the art. The vertical arrows within the vertically fractured portion 22 of oil shale formation 11 indicate the spalling and expansion of the oil shale into the void spaces formed by the leaching of layers 12 and 13.

Upon the development of a significant number of horizontal fissures 29, heating phase may be replaced by a production phase in which hot recovery fluid may be injected, or an underground combustion process conducted, as is well known in the art. If bypassing at the void space is too great, the injected reacting fluids may be injected over only limited intervals away from the permeable void channels. Alternatively, as illustrated in FIGURE 5 wherein like elements equal like parts of FIGURE 4, the reacting fluids may be injected through perforations 33 in well borehole 14 and into the bottom layer 13 and allowed to move upwardly through the oil shale layers 12 and 13 to be produced at the top of the oil shale out through perforations 34 in well borehole 18. Note that well boreholes 14 and 18 are packed off at packers 35 and 36, respectively. Also, the reacting fluid may be introduced at the top and produced at the bottom of the shale formation 11 as illustrated in FIGURE 6. Thus, the reacting fluid is injected down tubing string 27 above packer 37 and out perforations 30, adjacent void layer 12, down through oil shale formation 11 and back into production well borehole 18 through perforations 31. Finally, both top and bottom voids 12 and 13 may be filled by a material such as sand or propping sand by any means well known in the art. This is illustrated in FIGURE 7 wherein coarse material 38 is shown partially filling void spaces 12 and 13 thus reducing the tendency of injected fluids to flow through the void spaces. This increases the relative tendency of the injected fluids to flow through the fissures (such as fissures 29) and fractures (such as fracture 22) developed in oil shale formation 11 between the well boreholes as illustrated in FIGURES 5 and 6.

The composition of the reaction fluid is preferably adjusted to the extent required to circulate fluid that removes solid materials from the walls of the interconnecting channels without a significant reduction in the average rate of flow between the well boreholes so that the fluid flowing through the interconnecting channels, as for example fractures 19 and 22 and leached-out layers 12 and 13, is increased relative to fluid flowing between well boreholes 14 and 18. Solid-material removing components may be incorporated into the reacting fluid being circulated through the interconnecting channels without interrupting the flow to an extent that permits the channels to close and reseal. Such components may comprise hot benzene, steam, or other solvent, or nitric acid, of a lower temperature than the hot fracturing fluid. Nitric acid has the advantage of reacting with the organic matter as well as the carbonate present in the subterranean earth formation. The injection of such a reacting fluid leaches out part of the kerogen adjoining the faces of the interconnecting channels. The injection at a lower temperature and at substantially the same injection pressure permits the channels to open up and of the fluids. The temperature of the solid-material-removing fluid may be increased as the permeability of the interconnecting channels fractures 19 and 22 and layers 12 and 13, for example, is increased until the circulating fluid becomes hot enough to liquify the oil shale components of the subterranean oil shale formation 11.

Following the hot solvent injection as discussed hereinabove, acid may be injected to react with part of the rock matrix along the fracture walls. This acid injection renders the channels even more permeable.

After all the steps discussed hereinabove are carried out, an underground combustion process, as discussed hereinabove and is well known in the art, which develops considerably higher temperatures, may be undertaken. The steps of leaching out part of the kerogen and the rock generally make closure of the fracture paths during combustion very unlikely. In this manner, it is possible to treat a substantial part of the formation by underground combustion.

We claim as our invention:

1. In a method of recovering shale oil from a normally impermeable subterranean oil shale formation having at least one water-soluble mineral layer disposed therein comprising the steps of:

   extending at least a pair of well boreholes into said oil shale formations into communication with said mineral layers;

   forming generally vertical fractures extending along generally parallel paths from each of said pair of well boreholes;

   injecting hot fluid through at least one of the well boreholes until flow into at least one of the fractures therein is thermally closed by the swelling-shut of the walls of said fractures;

   pressurizing fluid in at least one well borehole in which at least one fracture has been thermally closed until at least one new fracture is formed;

   repeating the steps of injecting hot fluid and the pressurizing of fluid at successively higher temperatures and pressures until the resultant fractures from a channel interconnecting said well boreholes is through which fluid flows from one well borehole to another;

   circulating hot fluid by injecting it into one of said well boreholes opening into said fracture channel and producing it from another of said well boreholes opening to said fracture channel at a temperature below that at which the last fracture was thermally closed within the well borehole into which said hot fluid is injected but above that at which the last fracture was thermally closed within the well borehole into which said hot fluid is injected so that most of the injected fluid is conveyed through said fracture channel from one well borehole to another;
leaching portions of said water-soluble mineral layers that are exposed along said fracture channel by circulating aqueous fluid through said fracture channel; and producing shale oil by circulating fluid capable of converting kerogen to fluid petroleum materials through said subterranean oil shale formation and recovering petroleum materials from the outflowing fluid.

2. The method of adjusting the composition of said circulating hot fluid to the extent required to circulate fluid that removed solid materials from the walls of the channels interconnecting said well boreholes without a significant reduction in the average rate of flow between the well boreholes so that the effective permeability of fractures interconnecting said well boreholes is increased relative to that of other fractures.

3. The method of claim 2 including the step of increasing the temperature of the circulating hot fluid as the permeability of said well-interconnecting fracture channel increases to the extent required to circulate fluid that is hot enough to liquefy the oil shale components of the solid materials removed from the walls of said fracture channel.

4. The method of claim 3 including the step of recovering hydrocarbons from the oil shale components of the circulating fluid.

5. The method of claim 3 including the step of initiating an underground combustion within said subterranean earth formation.

6. The method of claim 2 wherein the step of adjusting the composition of said circulating fluid includes the step of incorporating aqueous acidic components into said circulating fluid.

7. The method of claim 1 including the step of recovering water-soluble mineral components from outflowing portions of said circulating aqueous fluid.

8. The method of claim 7 including the step of at least partially filling said leached-out mineral layers with fragments of oil shale that are detached from the surrounding oil shale formation.

9. The method of claim 8 wherein the step of circulating hot fluid includes circulating said hot fluid down said plurality of well boreholes, through said well-interconnecting fracture channel and out said central well borehole.

10. The method of claim 8 wherein the step of circulating hot fluid includes circulating hot fluid down said central well borehole, through said well-interconnecting fracture channel and out said plurality of well boreholes.

11. The method of claim wherein the step of circulating said aqueous fluid includes the step of injecting said aqueous fluid down at least one of said well boreholes through at least one mineral layer disposed at substantially the bottom of said oil shale formation, upwardly through said fracture channel, through at least one mineral layer disposed at substantially to top of said oil shale formation and out at least another of said well boreholes.

12. The method of claim 1 wherein the step of circulating said aqueous fluid includes the step of injecting said circulating fluid down at least one of said well boreholes, through at least one mineral layer disposed at substantially the top of said oil shale formation, downwardly through said fracture channel, through at least one mineral layer disposed at substantially the bottom of said oil shale formation and out at least another of said well boreholes.

13. The method of claim 1 wherein the step of extending at least a pair of well boreholes into said oil shale formation includes the steps of: extending a central well borehole into said formation; and extending a plurality of well boreholes into said formation whereby said plurality of well boreholes form a substantially geometric pattern in said formation with said central well borehole located substantially at the center of said pattern.

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U.S. Cl. X.R.

166—259, 271, 272; 299—5