LATERALLY EXPANDING OIL SHALE PERMEABILIZATION

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An improved process of permeabilizing and recovering water soluble and/or heat sensitive minerals and hydrocarbons from an oil shale formation containing said minerals by forming a cavern and vertically expanding it by contacting the cavern roof with a hot aqueous fluid while also causing horizontal expansion of the cavern by contacting the oil shale therein with the same or different hot aqueous fluid at a relatively shallow depth and flowing down along a vertical section while dissolving said minerals and rubbing the oil shale and producing from a relatively deep location in the cavern an aqueous liquid containing dissolved minerals therein and subsequently or simultaneously injecting a pyrolyzing fluid into the rubbed oil shale cavern to effect pyrolysis of the oil shale and recovery of hydrocarbons therefrom.

6 Claims, 3 Drawing Figures
OUTFLOWING COOL FLUID
INFLOWING HOT FLUID
INERT LIGHT FLUID

INFLOWING HOT FLUID
OUTFLOWING COOL FLUID

HORIZONTAL EXPANSION
VERTICAL EXPANSION

INFLOWING STEAM
OUTFLOWING LIQUID
OUTFLOWING GAS

FIG. 1
FIG. 2
FIG. 3

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LATERALLY EXPANDING OIL SHALE PERMEABILIZATION

This application is a continuation-in-part of copending patent application Ser. No. 57,209 filed July 22, 1970, now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to production of hydrocarbons and/or water soluble and/or heat sensitive minerals from underground oil shale formations by controlled circulation of a hot aqueous fluid through said oil shale formation so as to vertically and horizontally expand a permeable zone of rubbed oil shale within said formation by leaching and recovering said minerals from a relatively deep location within the treated area of the formation and thereafter injecting a pyrolyzing fluid into the rubbed oil shale to effect pyrolysis and recovery of hydrocarbons therefrom.

Various methods have been proposed for imparting permeability to underground oil shale formations such as fracturing by hydraulic or explosive means and/or acidization but they have proven to be ineffective and/or too expensive to use. Thus, oil shale formations which have been fractured on subsequent pyrolysis with pyrolyzing fluid to effect oil recovery, such fractures tend to close unless high pyrolyzing fluid circulation pressures at least equal to the overburden pressure, are maintained and this is difficult to do. Acidization of an oil shale formation is expensive and difficult to control.

SUMMARY OF THE INVENTION

The present invention is directed to an improved method of recovering hydrocarbons and water-soluble carbonates and/or heat sensitive materials from underground oil shale formations containing substantial amounts of said carbonate and/or minerals by forming a cavern therein by leaching with an aqueous fluid said carbonates and/or minerals and imparting permeability while effecting rubbing of the oil shale in said treated area by contacting and flowing a hot aqueous fluid downward from a relatively shallow depth along a vertical interval of said treated oil shale to cause horizontal expansion and recovering from a relatively deep depth an aqueous liquid containing dissolved therein water-soluble carbonates and/or heat sensitive minerals and subsequently injecting a pyrolyzing fluid or solvent to effect recovery of hydrocarbons from the rubbed oil shale.

DESCRIPTION OF THE DRAWING

FIG. 1 is a vertical section showing a subterranean oil shale and downhole equipment for practicing the present invention.

FIG. 2 is a schematic illustration of a flow path for circulating fluid in accordance with the present invention.

FIG. 3 is a vertical section showing an alternative arrangement of downhole equipment of the type shown in FIG. 1.

DESCRIPTION OF THE INVENTION

The present invention is in part premised on a discovery that, in a cavern within such an oil shale, the rate at which a hot aqueous fluid is segregated into layers having increasing densities, has been found to be related to the rate at which heat can be transferred into the walls of the cavern in a manner conducive to the establishing and maintaining of the flow path described above, and the resultant heating and leaching along substantially vertical portions of the walls of such a cavern has been found to cause a horizontal expansion of the cavern.

The term "cavern" is used to refer to any relatively solid free opening, such as a cave, void, tunnel, borehole, or interconnected fractures, etc., in which the rate of gravity segregation of fluids is not significantly impeded by a lack of permeability.

In the present process, the fluid circulation and cavern expansion operations can be initiated by opening at least a single well into an interval of oil shale that contains heat sensitive minerals and/or water soluble carbonates, inflowing hot fluid into contact with a upper portion of the borehole wall, flowing the hot fluid downward along the borehole wall, and removing liquid containing dissolved minerals and/or water-soluble carbonates from a lower portion of the borehole. Alternatively, a plurality of wells can be used to provide flow paths into a horizontally extensive cavern in or adjacent to oil shale that contains heat sensitive minerals and/or water-soluble carbonates and the wells and the cavern can be utilized to cause a concurrent horizontal and vertical expansion of a permeable zone by inflowing hot aqueous fluid into contact with a upper portion of such oil shale, flowing fluid downward along a vertical interval of such oil shale, flowing fluid horizontally along the roof of the cavern, and removing liquid containing dissolved minerals and/or water-soluble carbonates from within the cavern.

As used herein, the term "heat sensitive and/or water-soluble carbonate" refers to materials that decompose relatively rapidly at a relatively low temperature, such as one between about 250° F to about 700° F, to yield carbon dioxide and water. Examples of heat sensitive carbonate minerals include nahcolite, dawsonite, trona, and the like, minerals, which are usually inclusive of saline carbonate and/or bicarbonate molecular structures or moitites.

In a preferred embodiment of the present invention, a borehole is drilled into a relatively low-lying portion of oil shale which contains or is adjacent to a layer or region that is relatively rich in water soluble mineral. Such water soluble minerals (generally saline minerals) are frequently encountered in oil shale formations in the United States, such as the Green River formation in Colorado, in the form of beds, lenses, nodules, nodes, veins or the like. Examples of such water soluble minerals include the alkali metal chloride salts such as halite minerals and/or water soluble heat sensitive carbonate minerals such as nahcolite, trona, or the like.

The locations of portions of subterranean oil shales which contain specific mineral components, such as heat sensitive carbonate minerals and/or water soluble minerals, can be determined by means of known geological investigation procedures and equipment. In a preferred embodiment of the present invention, geological investigation procedures are utilized to locate a
portion of oil shale that contains heat sensitive carbonate mineral and is underlain by a portion or layer that contains water soluble mineral. The water soluble mineral is solution mined or leached for example, by means of a process of the type described in copending patent application Ser. No. 770,964; filed Oct. 28, 1968, now abandoned, and Ser. No. 860,349; filed Sept. 23, 1969, now abandoned. Those applications describe procedures for utilizing a water soluble mineral-rich portion of an oil shale to form a cavern that can be expanded before or during the recovery of shale oil from the oil shale exposed in and around the cavern. Such a solution mined cavern in or adjacent to an oil shale that contains heat sensitive carbonate mineral can advantageously be utilized as a horizontally extensive cavern that is expanded vertically during the horizontal expansion of a vertically extensive cavernous zone, such as a section of a borehole.

Referring to the drawing, FIG. 1 shows a portion of a well borehole 1 which has been drilled through an overburden 2, comprising successively shallower earth formations, and opened into an oil shale formation 3 that contains a heat sensitive carbonate mineral. The oil shale formation that is placed in fluid communication with a portion of the borehole to be used in practicing the present invention, should be a formation containing a significant proportion, e.g., greater than 5 percent by weight, of heat sensitive carbonate mineral. Borehole 1 is equipped with a string of casing 4, which is bonded to the surrounding earth formations by cement 5.

Separate conduits for conveying fluids between a surface location and, respectively, relatively shallow and relatively deep depths within the oil shale are provided by tubing strings 7 and 8. Alternatively, such conduits may comprise two or more parallel strings of tubing and may be located in two or more well boreholes that intersect or extend into a common cavern within the oil shale. Such conduits can be installed and equipped by means of known procedures and devices and heat insulation (not shown) is preferably installed around at least those of such conduits that are used for the inflow of hot fluid.

As indicated by FIG. 1, the vertically extensive cavern or opening that is expanded by the present process can comprise the borehole of a well that extends into an interval of oil shale that contains heat sensitive carbonate material. Such an interval preferably has a vertical thickness of at least about 100 feet. In the initial stages, such a borehole may have a generally cylindrical form, such as indicated by the dotted line 1a, and may comprise a relatively slender, generally vertical cavern within the oil shale. In operating the process with the equipment shown in FIG. 1, a hot aqueous fluid is flowed into contact with the wall of the cavern by inflowing hot aqueous gas and/or liquid through the annulus within pipe 8 (i.e., the space between pipes 7 and 8) and through adjacent perforations 6 at a relatively shallow depth within the carbonate mineral-containing portion of the oil shale. The inflowing fluid such as hot water and/or steam flows downward along the face of the vertical interval of oil shale (along the wall of the borehole) and decomposes and dissolves the heat sensitive carbonate mineral material. The dissolving of water soluble material forms a liquid solution 9. This solution, which is usually mixed with at least some gas, such as carbon dioxide and gaseous hydrocarbon, is out-flowed through pipe 7, which extends to a relatively low level within the borehole. The decomposing and dissolving of carbonate mineral components of the oil shale causes the spalling and caving in of particles 10 of the oil shale and causes a generally horizontal expansion of a rubble-containing cavernous zone of permeability within the oil shale.

Where the oil shale being treated contains a significant proportion of a mineral, such as a halite, which is water soluble in its natural form, the inflowing of hot aqueous fluid can advantageously be preceded by a circulation of aqueous liquid at a relatively low temperature, such as the wellhead temperature, the temperature of the source of the liquid or the like. In such a pretreatment, the circulating liquid may leach out significant portions of distributed layers or particles of the soluble mineral. This increases the surface area of the exposed oil shale or/and weakens the support for layers or chunks of the oil shale. Such a pretreatment circulation can advantageously be continued while the rate of dissolution is high, e.g., as indicated by the proportion of solute in the outflowing liquid. The so-circulated aqueous liquid can then be gradually or rapidly heated to the temperature selected for the inflowing hot aqueous liquid used to decompose heat sensitive carbonate material, with or without an interruption of the flow through the cavern.

When necessary or desirable the vertical expansion of the cavern can be inhibited by spotting and maintaining a relatively light and cool fluid 13 along the roof of the cavern. Such a fluid is preferably a gas and can in inflowed, or maintained substantially stationary, in and around the annulus within casing 4 (i.e., the space between pipe 8 and casing 4) and the upper portion of borehole 1 (below cement 5) to extend along the roof of the horizontally expanding cavern as the walls of the cavern more radially outward to and beyond the location shown at 1b.

The hot aqueous fluid used in the present cavern-enlarging procedure is preferably steam, hot aqueous liquid (hot water) or a mixture of such fluids. The hot fluid is preferably inflowed at a temperature, e.g., at least about 250°F, that is significantly higher than the normal temperature of the strata and/or oil shale formation. The heat transported by such a hot fluid converts the heat sensitive carbonate material to carbon dioxide and water vapor within portions of the normally impermeable oil shale matrix. Such a generation of gas causes localized fracturing and/or spalling of the oil shale.

The aqueous liquid component of the inflowing hot fluid dissolves water soluble mineral material and creates additional solid-free void space. This occurs along most, if not all, of the vertical extent of the flow path used in the present process. The spalling and dissolution causes a horizontal expansion of a rubble-containing cavern. The inflowing hot aqueous fluid can comprise super heated, dry, or wet steam, or a mixture of such a steam with substantially any gas vapor or liquid, such as carbon dioxide, phenols, hydrocarbons, alcohols, halogenated hydrocarbons, acids, or the like, or with substantially any aqueous solution, such as an aqueous acid or base or solution or neutral salt. Where the inflowing fluid is substantially completely gaseous it should contain sufficient steam to provide a significant amount of aqueous liquid as it condenses within the cavern.
The inflowing hot aqueous fluid can be heated by means of surface located and/or downhole located, steam generators, water heaters, or the like. Alternatively, or additionally, such heating can be effected or supplemented in an insitu combustion within the oil shale formation. The temperature of the inflowing hot aqueous fluid can range from about 250°F to one sufficient to cause a relatively rapid oil shale pyrolysis, e.g., a temperature of from about 600°F to 1000°F.

The inflowing aqueous liquid phase of the hot aqueous fluid dissolves naturally water soluble minerals such as nathcolite, trona, halite, or the like, and/or water soluble decomposition products from a heat sensitive carbonate material, such as nathcolite, etc., to create solid-free space within the oil shale. Various water soluble minerals, such as nathcolite (NaHCO₃), may dissolve prior to any thermal decomposition, if the pressure is sufficiently high at the temperature of the inflowing fluid. Alternatively, such minerals may be partially or wholly decomposed to gaseous fluids and sodium carbonate before dissolution.

Although the portion of oil shale formation which is treated in accordance with the present invention must contain a significant amount of heat sensitive carbonate material, it may contain sections, or vertical intervals of as much as several tens of feet thick, which are substantially devoid of heat sensitive and/or water soluble minerals. In such heterogeneous regions, the heat sensitive or soluble minerals are converted or dissolved and removed. Portions of the so-converted oil shale materials become incompetent and break into pieces under the existing local stress field. Such pieces, or chunks, of oil shale material tends to accumulate on the top of ledges of oil shale that contains little or no heat sensitive or soluble material. The accumulation of weight from such chunks, together with the existing stress field, cause such ledges to break into pieces and fall to a lower level. The action of converting kerogen into shale oil materials such as gaseous and liquid hydrocarbons enhances such an operation and, where the oil shale is relatively lean with respect to heat sensitive and soluble materials, the use of hot aqueous fluid heat to a kerogen-pyrolyzing temperature is desirable. Also hydrocarbons can be extracted from the rubbed oil shale by solvent means such as by use of phenols, aromatic solvents, e.g., benzene, xylene, etc.

Due to mechanisms such as those mentioned above, the application of the present process causes a generally vertical cavernous zone to grow in a horizontal direction. The rate of growth will vary depending upon the heat sensitive and water soluble mineral content of the particular zone. The outer boundary of the zone will generally be very irregular with portions extending several tens of feet further than others. In order to enhance horizontal growth while injecting a hot aqueous fluid that is predominantly liquid, it is generally desirable to maintain most or all of the rubbly-containing cavern full of liquid. Alternatively, where the injected hot aqueous liquid is steam, it is generally preferably to keep much of the rubbly-containing kerogen filled with steam and/or gas.

A particularly suitable arrangement of flow paths to be used in the present process is shown in FIG. 2. At least two horizontally separated wells are opened into a region of oil shale that contains heat sensitive carbonate mineral and is located immediately above a layer or zone of oil shale or other earth formation material that is rich in water soluble mineral and/or heat sensitive carbonate mineral. Such wells are used to form an inflow path 14 and an outflow path 15 that are interconnected by a path extending through an areally extensive cavern 6. As indicated by the arrows, hot aqueous fluid is inflowed in contact with oil shale containing heat sensitive carbonate material at a relatively shallow depth, flowed down along a vertical section of such oil shale, flowed along the roof of a horizontally extensive cavern within such oil shale, and, liquid containing dissolved mineral material is removed from within the horizontally extensive cavern. Such a horizontally extensive cavern can advantageously be formed by means of mechanical fracturing, and/or solution mining techniques, for example, by one or more of such techniques described in the above mentioned pending patent applications.

A principle advantage of a flow path of the type shown in FIG. 2 is the heat economy and the fact that much larger volumes of oil shale can be rubbed per unit time than could be achieved by either a horizontal or vertical rubbing by itself. Relative to horizontal rubbing from a single well, the concurrent vertical and horizontal rubbing is capable of providing much higher oil production rates, particularly in the early stages of the process. Such a flow path can be utilized to produce a relatively cool fluid with much of the produced hydrocarbon and injected fluid being outflowed in the liquid phase.
horizontally separated patterns that each contain one or more wells opening into a layer rich in water soluble minerals can be operated as described in connection with FIG. 2 to form horizontally expanding permeable zones and produce shale oil. The sizes of the permeable zones can be monitored by means of acoustic, electromagnetic the like measurements of the extents of the substantially void space and/or measurements of the volume of fluids that are contained into caverns. The horizontal expansion of the caverns can be controlled to provide an efficient recovery of oil from nonintersecting, generally vertically extensive zones that are spaced so that undisturbed columns capable of supporting the overburden are left between the depleted zones.

During the initial stages of expanding a rubble-containing cavern in accordance with the present process, it is not necessary and is generally undesirable to use a temperature high enough to decompose a predominant proportion of the fluid-contacted heat sensitive carbonate material. It is preferable to keep the cavern substantially full of aqueous liquid in which the carbonate material is soluble. This tends to provide the best heat economy since it minimizes the decomposition reaction (which is an endothermic reaction that consumes heat). In order to keep the cavern substantially filled with aqueous liquid it is preferable to maintain the pressure within the cavern above the decomposition pressure of the heat sensitive carbonate material at the temperature within the cavern. In general the pressure within the cavern cannot be kept high enough to prevent such a decomposition during an oil recovery stage. The retorting and hydrocarbon recovery is preferably conducted at a temperature above about 500°F, and at the depths at which oil shale is usually encountered, the pressure in the cavern cannot be high enough to prevent decomposition of heat sensitive carbonate material at such a temperature, without a danger of creating large scale fractures which are extended in a location with such fractures are undesirable.

When one or a plurality of generally vertically extensive permeable zones have been expanded horizontally to substantially the extent desired, the circulation of fluid within throne zones or caverns is preferably adjusted to minimize the rate of horizontal growth and/or maximize the rate of oil recovery. Such an adjustment can be effected by increasing the temperature and/or decreasing the aqueous liquid content of the fluid within the cavern. A higher temperature tends to increase the rate of oil recovery (particularly with respect to the gaseous components of shale oil). Alternatively, a decrease in the aqueous liquid content tends to reduce the rate of dissolution of soluble mineral. Where the removal of solid material from the oil shale is confined to a removal of the fluid products of the pyrolysis reaction and/or the CO₂ and water vapor produced by the decomposition of heat sensitive carbonates, the volume of the depleted oil shale tends to be sufficient, relative to the volume of solids that are removed, to terminate the growth of the permeable zone (unless the oil shale is one that contains an exceptionally large proportion of heat sensitive carbonate mineral). The aqueous liquid content of the fluid within the cavern can be reduced by, for example, circulating substantially dry steam, or a mixture of a dry steam and e.g., carbon dioxide, at a rate and temperature at which the outflowing fluid is predominately gaseous and the aqueous liquid lift within the cavern contains a relatively high proportion of inert inorganic solute.

FIG. 3 shows downhole equipment of the type shown in FIG. 1 arranged to effect a downhole separation of the gaseous and liquid phases of the fluid being produced. Particulatively when the concentration of heat sensitive carbonate material is relatively high, and/or the temperature of the inflowing hot aqueous fluid is relatively high, a significant amount of gaseous carbon dioxide and water will be formed. However, to the extent that it is feasible, it is desirable to produce a relatively cool liquid phase fluid that contains a significant proportion of produced shale oil hydrocarbon. In the arrangement shown in FIG. 3, borehole 20 is equipped with pipe strings 21, 22 and 23. Some or all of such pipes are preferably thermally insulated, as indicated by coatings 24 on pipes 21 and 22. Pipe 21, through which the hot aqueous fluid is inflowed, opens into the borehole at a relatively shallow depth. Pipe 22 extends to an intermediate depth and is used to outflow fluid that is relatively cool but is predominately gaseous. Pipe 23 extends to a relatively deep depth, is preferably equipped with downhole pumping means (not shown), and is used to outflow fluid that is predominately liquid.

The vertical section of borehole between the ends of pipes 22 and 23 serves as a downhole gravity of separation chamber.

Steam or a mixture of steam and hot aqueous liquid (hot water) is inflowed through pipe 21. The inflowing hottest and lightest gas tends to remain above the cooler and heavier gas and in situ generated carbon dioxide. The cooler gases outflow through pipe 22 while the hotter and lighter inflowing gases tend to flow along the walls of the cavern. Where desirable a relatively light and cool gas, such as methane, hydrogen, etc., can be maintained substantially static, or slowly injected, through and around the upper portion of the borehole and cavern.

Once the rubbed oil shale cavern has been established and the heat sensitive minerals and water-soluble carbonates removed as an aqueous solution, the hydrocarbons (oil) can be recovered by suitable means such as by contacting the rubbed oil shale within the cavern with a pyrolyzing fluid to effect decomposition of the kerogens to hydrocarbon which is removed from the formation. In recovering the hydrocarbons, the pyrolyzing fluid can be injected (FIG. 1) via 7 and recovered via tubing 8 visa versa and in a dual system as shown in FIG. 3 the pyrolyzing fluid such as steam can be injected via tubing string 21 and the hydrocarbons recovered via 22 or the process can be reversed.

It is understood that various changes in the detailed described to explain the invention can be made by persons skilled in the art within the scope of the invention as expressed in the appended claims.

I claim as my invention:

1. In a process for expanding a zone of permeability within a subterranean oil shale by forming a permeable zone within a portion that contains heat sensitive carbonate mineral and circulating hot aqueous fluid within the permeable zone, the improvement which comprises:

inflowing hot aqueous fluid into contact with a subterranean portion of oil shale that contains heat sensitive carbonate mineral at a relatively shallow depth, the temperature of said inflowing fluid being high enough to pyrolyze oil shale;
flowing a mixture of a hot aqueous fluid, gaseous carbon dioxide and hydrocarbon downward along a vertically extensive portion of oil shale that contains heat sensitive carbonate mineral, from said relatively shallow depth to a deeper depth;
outflowing an aqueous solution of mineral material from a relatively deep depth, in order to cause a horizontal expansion of a rubble-containing cavernous zone within said oil shale;
recovering shale oil with said outflowing fluid.

4. A process of expanding a fluid permeable opening within a subterranean oil shale formation, comprising: establishing separate paths of fluid communication between a surface location and upper and lower portions of a relatively solids-free opening within a subterranean oil shale formation that contains heat sensitive carbonate material; inflowing relatively hot and relatively low density aqueous fluid into contact with the oil shale around the upper portion of said opening at a temperature sufficient to cause a localized removal of solid material from the oil shale; removing cooler and heavier fluid from the lower portion of the opening within said oil shale formation at a rate correlated with the rate of fluid inflow to maintain a layer of relatively hot and low density aqueous fluid above a layer of relatively cooler and higher density aqueous solution of mineral material; and continuing said fluid circulation to cause a generally horizontal expansion of the opening within said oil shale formation due to a decomposition dissolution of solid components of the oil shale.

5. The process of claim 4 in which said subterranean oil shale formation contains at least about 5 percent by weight of heat sensitive carbonate material.

6. The process of claim 4 in which:
said solids-free opening and at least one of said paths of fluid communication is extended into an areally extensive opening within an adjacent underlying zone that is rich in water soluble mineral; and said fluid circulation is adjusted to cause a generally vertical expansion of said underlying opening concurrent with said generally horizontal expansion.