Sept. 14, 1965 C. R. SANDBERG 3,205,942

METHOD FOR RECOVERY OF HYDROCARBONS BY IN SITU
HEATING OF OIL SHALE
Filed Feb. 7, 1963

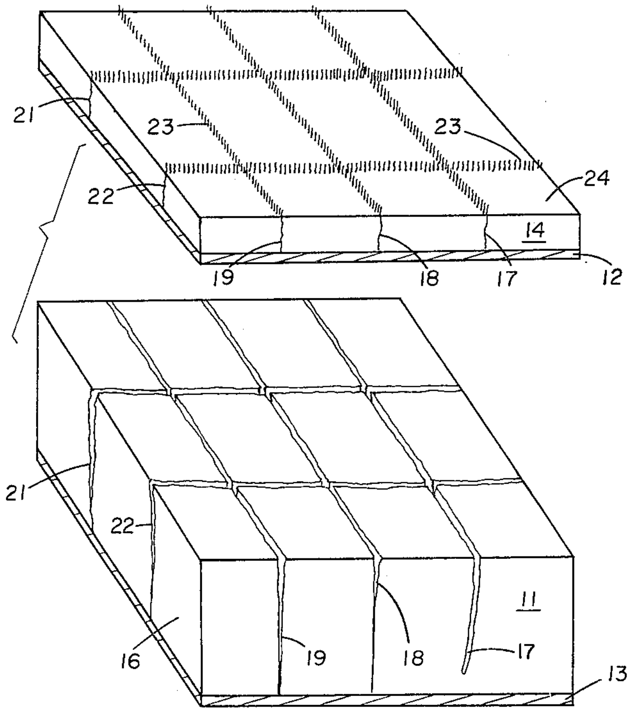

FIG. 1.

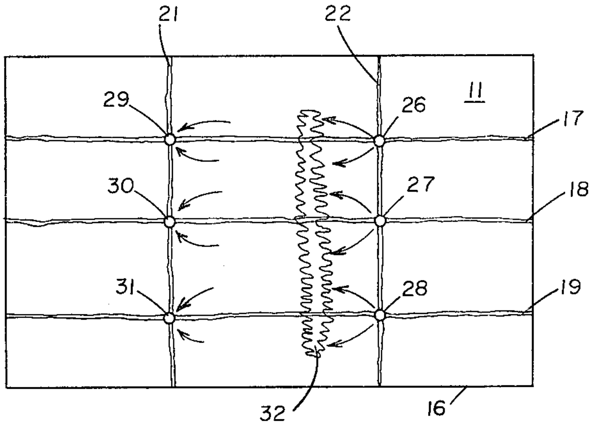

FIG. 2.

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3,205,942
Patented Sept. 14, 1965

3,205,942

METHOD FOR RECOVERY OF HYDROCARBONS BY IN SITU HEATING OF OIL SHALE

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Filed Feb. 7, 1963, Ser. No. 256,906
19 Claims. (Cl. 166—4)

This invention relates to a method for recovering hydrocrabons from an oil shale by in situ heating. More particuarly, it relates to a method utilizing the existing fractures and the nautral fluid permeable properties of the oil shale formation for maximum recovery of shale oil.

Oil shale must be heated or retorted to obtain crude shale oil. Many methods have been proposed for recovering shale oil from massive subterranean formations of oil shale in their natural environment. No known method has been developed for in situ recovery of shale oil which is economically satisfactory. One reason is that the permeability of massive oil shale prior to retorting, outside of any natural fracture systems, is exceedingly small. Thus, some methods require extensive fracturing steps to produce the desired fluid permeability in the oil shale for passage of the heating or combustion-supporting fluids required to retort the shale. The excessive cost of arbitrarily creating sufficient fractures to provide the desired fluid permeability in most cases forecloses the commercial use of such methods. Other methods which rely upon the permeability provided by the natural fracture systems and interposed tuffaceous strata in the oil shale are ineffective for commercially retorting the oil shale. One reason is that the tuffaceous strata has a permeability nearly as small as that of the oil shale because of bituminous materials sealing the pore spaces. Sufficient fluid permeability to permit the horizontal flow of the heating or combustion fluids can be obtained only after heating such strata to oil shale retorting temperatures to remove the bituminous material. Therefore, the methods using tuffaceous strata for initially providing fluid communication for heating the shale contain an inherent defect which prevents their commercially satisfactory operation. Other methods rely upon the natural fracture systems for the fluid permeability needed for in situ retorting of oil shale. These methods are not satisfactory because only by accident is sufficient fluid permeability obtained for efficient in situ heating. These methods are inoperative for most practical purposes because their operation is based upon the assumptions that the oil shale predominantly contains horizontal fractures and that the natural fluid permeability is uniform in all horizontal directions along the existing fractures.

It is therefore an object of this invention to set forth the reasons for the unsucessful operation of the prior methods of shale oil recovery and to provide a unique solution to the problem of economical in situ heating of certain massive shale to provide shale oil.

Another object of this invention is to provide a novel method for recovering shale oil by in situ heating of the hydrocarbon materials in the shale.

Another object is to use the natural fluid permeable properties with the existing fractures of the oil shale in steps in the method of this invention for placing a plurality of wells to provide for the effective recovery of hydrocarbons from massive subterranean oil shale formations.

Another object of this invention is to provide a method including steps for determining and correlating the natural fluid permeable properties with the natural fractures of the shale so that in situ retorting of oil shale can be obtained without the deficiencies present in heretofore known shale oil recovery methods.

These and other objects will become more apparent when read in conjunction with the following detailed description, the appended claims, and the attached drawing wherein FIG. 1 shows an illustrative embodiment of the method of the present invention applied to a subterranean formation of oil shale with the view in isometric perspective consisting of a block of massive oil shale in exploded relationship with a superimposed covering of overburden; and FIG. 2 is a plan view similar to the oil shale block of FIG. 1, but showing a plurality of wellbores in fluid communication with the natural fractures of the oil shale.

The objects of the present invention are achieved by utilizing the natural fractures with the existing fluid permeability in the oil shale formation in the steps of locating a plurality of formation-penetrating wells, and determining the nature of use as injection and production wells for optimum recovery of shale oil by in situ heating of the oil shale.

Referring now to FIG. 1 of the drawing, a detailed description of an illustrative embodiment of the method of this invention will be given. Massive oil shale **11**, when subjected to an extensive geological survey, shows that the natural fracture systems consist of predominantly vertical or near vertical fractures. For example, a shale which has been subjected to a tectonic uplift contains this fracture system. One example of such oil shale is the Parachute Creek member of the Green River formation in Colorado. This massive oil shale contains vast quantities of hydrocarbons in the form of kerogen. For practical purposes, there are no horizontal fractures present which effect fluid permeability to any significant extent. The vertical fractures of such system are of relatively small vertical dimensions but they are extensively interconnected so as to functionally appear continuous, as shown in FIG. 1. Approximately 50 percent of the fractures are vertical and the remainder are nearly vertical, having dips ranging from 70° to 85° from the horizontal. The term "fracture" as used herein is intended to include all types of crevices of high fluid permeability whether open or filled with debris.

Further, the most prominent of the natural fractures are aligned in substantially one horizontal direction. This may be denoted as the regional fracture trend. Stated in another way, the majority of the fractures will be aligned in one direction with the remainder of the fractures being aligned in a different direction with substantial interconnection between fractures. In addition, it has been found that the fracture system of the shale residing below the overburden is unique in that about 98 percent of the vertical fractures are spaced within a certain relatively short distance from one another. This distance is less than 12 feet at depths up to 200 feet, as determined by a geological survey. However, this distance may slightly vary with depth and locality. Interimposed along the horizontal in such massive shales are various tuffaceous strata **12** and **13**. A surface overburden **14** is generally present and may have a thickness up to 1000 feet or more. As previously mentioned, the tuffaceous strata **12** and **13** are initially impervious to fluids because of the contained bituminous materials. These tuffaceous strata **12** and **13** provide horizontally disposed fluid barriers at determinable vertical spacings in the oil shale. It will be apparent that with the vertical disposition of the natural fracture system or trend, attempts to produce it on the assumption of an existing horizontally disposed fracture system can only result in inefficient production of shale oil. The reason is that the various wellbores penetrating such formation cannot be placed at optimum locations for maximum fluid communication with the existing vertical fractures. Further, the tuffaceous strata **12** and **13** or other impermeable nonshale structures may be interposed between the wellbores and the oil shale desired to be produced.

More particularly, in FIG. 1 there is shown a regional natural fracture trend wherein the vertical fractures **17**, **18**, and **19** are predominantly disposed in one horizontal direction in parallelism to side **16** of shale **11** and represent the most prominent fractures. The remaining lesser fractures are represented by interconnected vertical fractures **21** and **22** aligned in a different horizontal direction. It is to be understood that in actuality there are a multiplicity of fractures paralleling those shown in FIG. 1 which are not illustrated in order to preserve the clarity of the drawing. A geological survey is performed to locate sufficient numbers of these natural fractures in the formation so as to determine the disposition of the regional fracture trend by their alignment in horizontal directions as one step in the method of this invention. This survey can be obtained by visual observation of the earth's surface. For example, grass or other vegetative growth **23** on the earth's surface **24** will be in alignment with most of the fractures below the surface of the earth. This growth is believed prompted by the accumulation of moisture in the fractures in an area which is quite arid. Thus, the vegetation, particularly the grass, can be observed to grow in straight lines superimposed above most of the fractures. Also, the disposition of some of the fractures can be seen at the exposed cliffs of oil shale and in various mines in the immediate area. The geological survey also can be performed by systematically drilling and coring the oil shale **11** to be retorted. The regional fracture trend and location of fractures is obtained by displaying the fracture orientations present in each core on a topographic map representing the desired area. Other means of performing geographic surveys or tabulating geological data can be used if desired.

Another step of this method is to determine the natural fluid permeability of the formation. This fluid permeability consists of the major and minor directions of fluid permeability, or fluid flows, in the oil shale **11**. This property may be determined by providing a plurality of wells **26** through **31**, as shown in FIG. 2, into the oil shale **11** and in fluid communication with the vertical fractures **17**, **18**, and **19** along the major fracture trend and the remaining fractures **21** and **22**, as located by the previous step. If these wells are not in fluid communication with the fractures over a substantial extent of their vertical dimension in the shale **11** to be retorted by direct intersection, suitable fracturing means may be used to effect the desired communication. Fracturing means such as hydraulic fracturing, explosives, and passing electric currents through the formation to fracture same may be used to provide the desired communication. Other fracturing means may be used if desired.

One means of determining the major and minor directions of fluid flow in the oil shale **11** is by injecting a tracer gas through one or more of the wells into the fractures and monitoring its appearance at the other wells. One suitable gas is the chemical compound dichlorodifluoromethane which is sold under the trademark Freon-12. Other types of tracer gases can be used. For example, the gas may be radioactive which will require the monitor to be capable of determining the radioactive quantum of the effluent gases.

The tracer gas is preferably pressured through the formation in an admixture with air from one or more wells. A suitable mixture may be formed of one part Freon-12 with 300 parts of air. For example, the tracer gas is injected through well **27** into the oil shale **11**. The wells **26** and **28** through **31** are vented to the atmosphere. The gaseous effluent of each of the vented wells is monitored by a suitable halogen detector, such as the General Electric model H-2 halogen detector. A correlation of the transit time of the halogen-containing gas to reach the vented wells with the distance of each well from the injection well **27** is made. The wells which reside in a direction from the injection well **27** in alignment with the major fluid permeability of the oil shale have the lowest ratio of transit time to distance of travel of the tracer gas. The wells having the largest ratio of transit time to distance of travel of the tracer gas reside in a direction in alignment with the minor fluid permeability of the oil shale. Preferably, tracer gas is injected through each of several wells, in succession, with the remaining wells being vented. This is more time-consuming but provides very detailed information as to the fluid permeable properties of the oil shale **11**. Other means of determining the major and minor directions of fluid permeability in the oil shale **11** can be used if desired. For example, fluid can be injected into one or more wells and the flow volume or pressure present at the remaining wells can be measured. Thus, the wells producing the greatest quantity of pressured fluid per unit distance from the injection well reside in alignment with the direction of major fluid permeability and the wells producing the lesser quantity of pressured fluid per unit distance reside in alignment with the minor fluid permeability of the oil shale **11**.

It was found in one locality that the relative fluid flow through the oil shale **11** in the major and minor directions of fluid permeability were in a ratio of about 8 to 1, and generally correlated to the disposition of the fractures. This indicates that the vertical fractures of the regional fracture trend provide for predominant fluid permeability in one direction. However, there is also some fluid permeability in a second direction. It will be apparent that the predominant fluid flow may not always be exactly in the same direction as the regional fracture trend because of the interconnection and flow properties provided by the existing vertical fractures in the oil shale **11**. This property is necessarily determined as it will determine the proper usage, as injection or production facilities, of wells which will be described hereinafter.

A plurality of wells penetrating the oil shale **11** are provided to carry out the method of this invention. These wells may already exist as a result of practicing the preceding steps. However, other wells may be provided. At least one injection well is provided in communication with a fracture **22** which is disposed generally along the direction of minor fluid permeability in the formation. Generally, such fracture **22** will extend in a horizontal direction other than in alignment with the fractures **17**, **18**, and **19** of the regional fracture trend. Preferably, a plurality of injection wells **26**, **27**, and **28** are spaced along the vertical fracture **22** or paralleling adjacent fractures. These wells **26**, **27**, and **28** can be spaced apart a distance approximately equal to the distance at which the major portion of the fractures are spaced from one another. For example, a spacing of 12 feet can be adequate where a majority of the fractures are spaced within this distance from one another. The injection wells **26**, **27**, and **28** should be in communication with the fracture **22** over a substantial portion of its length extending vertically through the vertical dimension of the block of oil shale **11** to be retorted. This vertical dimension can be the distance between the tuffaceous strata or other horizontally disposed natural fluid barriers that may be present. Where the wells **26**, **27**, and **28** are provided by drilling, the drilling techniques may be utilized to place them into the desired communication relationship with the vertical fracture **22** and fractures **17**, **18**, and **19**, respectively. However, auxiliary fracturing means may be used to provide this communication where it is not directly obtained. Fracturing means such as explosives, hydraulic fracturing, or passage of electrical currents through a formation can be used for this purpose. The wells **26**, **27**, and **28** can be placed into direct communication with one or more fractures **17**, **18**, and **19**, if desired, without relying upon fracture **22** for this purpose.

At least one production well is provided which is in communication with a fracture at a horizon to which the shale oil products flow along the regional fracture trend and disposed generally in the direction of major fluid permeability of the oil shale 11 from each injection well. Preferably, a plurality of production wells 29, 30, and 31 are provided along the fractures 17, 18, and 19 disposed generally in alignment with respect to the major fracture trend and along the direction of major fluid permeability from each of the injection wells 26, 27, and 28. The production wells 29, 30, and 31 are spaced from the injection wells 26, 27, and 28 by a distance sufficient to interpose the amount of oil shale 11 to be retorted between the wells. For example, a distance between the injection and production wells of approximately 5 to 100 feet may be found satisfactory. The production wells 29, 30, and 31 are placed into communication with the fractures 21, 29, 30, and 31 along a substantial part of their vertical height extending vertically through the vertical dimension of the block of oil shale 11 to be retorted. If desired, this vertical dimension can be the distance between the tuffaceous strata 12 and 13, or other natural fluid barriers that may be present. Auxiliary fracturing means may be used, as described in connection with the injection wells, where needed to provide this communication.

Suitable means may be provided the injection wells for injecting suitable gases to heat the oil shale 11 and the production wells for removing the shale oil resulting from the in situ retorting of oil shale 11.

It may be found desirable in certain situations to increase the fluid permeability between the wells for various reasons. One reason is to increase the amount of shale oil produced at the initial stages of the retorting. Another reason is to alter the major and minor direction of fluid permeability to be more suitable for a desired patterning of injection and production wells. The fluid permeability can be increased by acid treatment of the fractures between the wells to remove carbonates and other types of secondary deposits or debris which may be in the fractures. Also, passing nonacid fluids at high pressures and velocities through the fractures may be found effective for mechanically removing any deposits present therein. Water is one such fluid. Moreover, in some cases it may be found advantageous to increase the initial size of the fractures by using conventional hydraulic fracturing methods for opening and propping the fractures. Such methods can use a fluid containing sand and guar gum for this purpose.

Thus, the geological survey provides for the placement of wells into effective communication with the existing fractures in oil shale 11. The step of determining the major and minor directions of natural fluid permeability provides for use, as injection facilities, of the wells communicating with fractures along the minor direction of fluid permeability and, as production facilities, of the wells in communication with the fracture of the regional fracture trend along the major direction of fluid permeability from the injection wells.

As the next step, a heat-creating gas is supplied to the oil shale 11 to be retorted through one or more of the injection wells into the fractures 17, 18, 19, and 22, and concomitantly or subsequently, combustion is initiated in fracture 22, in the shale of the sidewalls surrounding these wells, and then along the fractures 17, 18, and 19 which provide for fluid communication between the injection and production wells. The combustion can be initiated by injecting a combustible material, such as fragmented oil shale or hydrocarbon fluids, into the wells 17, 18, and 19. The combustible material is ignited to heat the exposed oil shale to an ignition temperature. Means for directly igniting the formation can be used if desired. One such means may be an electric heater located with each of the injection wells. Other suitable formation igniting means can be used if desired.

The term "heat-creating gas" is used herein to include a gas selected from the group consisting of oxygen-containing gases singly or in various proportions and combinations with combustible and noncombustible gases. The heat-creating gas having oxygen-containing gases may be preheated initially at the surface by suitable equipment to a temperature sufficient to ignite spontaneously a portion of the hydrocarbon materials in the shale. The combustion of such materials produces heat to decompose the kerogen into shale oil and to drive the resultant hydrocarbon products from the shale. The heating begins with the shale surfaces adjacent each of the injection wells and produces a flame or combustion front 32 which migrates through the oil shale 11. The combustion front 32 moves progressively outwardly from the injection wells 26, 27, and 28 so as to provide a uniform heat front for driving the hydrocarbon products from the oil shale 11, along the fractures, principally of the regional fracture trend, and into the production wells 29, 30, and 31. Any of the wells not used in the heating of the oil shale formation or for production of shale oil products are sealed or shut in.

Once the combustion of the oil shale 11 is initiated, the temperature and the velocity of the heat or combustion front 32 can be regulated by adjusting the temperature of the heat-creating gas being introduced, or the volume of such gas, or its oxygen content as found best suited for maximum recovery of the hydrocarbons from the shale 11 as judged by the quantity of shale oil produced. The oil shale 11 is preferably heated to a temperature above 500° F. and preferably between 500° F. and 1100° F. Temperatures above 1100° F. decompose inorganic carbonates producing undesired carbon dioxide and may fuse the shale into an impermeable mass if above 2300° F. Temperatures below 500° F. are ineffective to decompose the kerogen portion of the oil shale 11 into shale oil products.

Combustible gases may also be injected into the oil shale 11 and therein ignited when the hydrocarbon content of the oil shale is relatively low and initiation of combustion is difficult, or for other reasons. Such combustible gases can provide the only fuel used for heating the shale or to supplement the hydrocarbons or kerogens present as natural fuel in such oil shale 11. The combustible gases may be injected into the oil shale 11 through one or more of the injection wells separately or in combination with oxygen-containing gases. It may be found desirable in certain aspects of operation to alternately inject the oxygen-containing gases and the combustible gases into the oil shale 11. Noncombustible gases may be admixed with the injected gases to assist in controlling the temperature of the flame front. Alternatively, such gases may be heated to temperatures sufficient to decompose the kerogen in the oil shale and to facilitate the recovery of hydrocarbons therefrom and used separately or in combination with the previously mentioned gases. The selection of any particular mode of injection of the heat-creating gas will depend upon the conditions existing in the shale formation. This step of in situ heating by injecting various gases is well known to those skilled in the art.

By these steps the combustion front 32 is driven through the fractures in fluid communication between the injection and production wells to effect shale retorting to produce the desired shale oil products. As previously mentioned, there are numerous fractures between the wells other than shown in FIGS. 1 and 2. Thus, one of the great advantages of this invention resides in the placement of the injection wells in communication with fractures disposed in general alignment with the direction of minor fluid permeability of the oil shale 11 whereby in the present illustrative example the combustion front will have an effective width at least as great as the distance between injection wells 26 and 28. Further, the travel of the combustion front 32 through the oil shale 11 is at least as great as the distance between the injection and production wells. The movement of the heat-creating gas driving the combustion front through the oil shale is indicated generally by arrows (unnumbered). Thus, optimum recovery of shale oil is provided.

The flow of the heat-creating gas at the boundaries of the oil shale **11** to be retorted is restricted to a greater extent by fluid friction than through the fractures in the medial portion of the shale. Therefore, the portions of the shale formation are not heated above or below the oil shale **11** desired to be retorted. Thus, any tuffaceous strata adjacent oil shale **11** generally are not heated sufficiently to reduce their bitumen content so as to undesirably increase their permeability. Thus, the shale oil products from oil shale **11** can be contained vertically by the nonheated tuffaceous strata or shale formation. The products are also horizontally contained and directed by the arrangement of the existing major and minor fluid permeability of the oil shale **11** with the placement of the injection and production wells to insure their recovery. The shale oil products can be removed to the earth's surface and conveyed to market by suitable hydrocarbon-collecting systems.

It is intended that the particular description of the combustion front **32** traversing oil shale **11** be taken as illustrative and not as limitative of the present invention inasmuch as several variations in passing a combustion front **32** through oil shale **11** can be made by persons skilled in the art. For example, the combustion front **32** may be interrupted to provide one or more nonburning intervals where the intense heat generated by the combustion front **32** can be used to heat the oil shale **11** by thermal conductivity. Thus, the oil shale **11** can be retorted by a composite of conductive and convective transferal of heat. One means for interrupting the in situ heating is by reducing the amount of the heat-creating gas to a point where it is insufficient to support combustion. However, other means to interrupt the in situ heating can be used.

Also, there may be several independent but successive combustion fronts **32** passed through oil shale **11** to produce the desired retorting to produce shale oil products. This mode of passing the combustion front **32** through the oil shale **11** would permit preheating of the oil shale **11** prior to the passage of the next successive combustion front **32**. This would reduce the viscosity of the shale oil products retorted by the next successive combustion front **32**.

The permeability of the oil shale **11** upon being retorted is sufficiently increased that the heat-creating gas can contact the unretorted oil shale in sufficient quantity to progressively retort successive portions of the oil shale **11**. Thus, the oil shale **11** within the rectangle formed between the injection and the production wells can be efficiently heated to retorting temperatures to produce substantially the major portion of available shale oil. Further, it has been found that horizontal fractures are formed after heating the oil shale **11** sufficiently to produce shale oil. These horizontal fractures also assist in permitting increasing quantities of the heat-creating gas to penetrate throughout the mass of oil shale **11**. This produces a homogenous retorting of the oil shale **11**.

From the foregoing it will be apparent that the method of this invention provides for placement of the injection and production wells in the oil shale in a manner to utilize the existing fractures and the natural fluid permeability in such manner that in situ combustion of the oil shale may be initiated in an effective and efficient manner without resorting to expensive auxiliary means or steps for retorting the oil shale formation.

Various changes and modifications of this invention may be made without departing from the scope thereof. This is contemplated in presenting this invention and is intended to be within the scope of the appended claims.

What is claimed is:

1. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to locate sufficient natural fractures to determine the regional fracture trend and the interconnecting natural fractures disposed in other horizontal directions,

(b) determining the major and minor directions of fluid permeability of the oil shale,

(c) providing at least one well in fluid communication with a natural fracture generally disposed along with the minor direction of fluid permeability,

(d) providing at least one well aligned with the major direction of fluid permeability from each first-mentioned well in fluid communication with a natural fracture aligned with the regional fracture trend,

(e) supplying a heat-creating gas through at least one of the wells provided by step (c) and initiating combustion in the oil shale adjacent at least one of the wells,

(f) driving a combustion front through the oil shale along the fractures in communication between said wells provided by steps (c) and (d) to effect retorting of shale oil products, and

(g) recovering the shale oil products from at least one of the wells in fluid communication with a natural fracture disposed along the major direction of fluid permeability from a well used for supplying the heat-creating gas.

2. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to locate the disposition of a plurality of natural fractures in horizontal directions,

(b) determining the major and minor directions of fluid permeability of the oil shale,

(c) providing a plurality of wells in fluid communication with the natural fractures generally disposed along with the major and the minor directions of fluid permeability,

(d) supplying a heat-creating gas through the wells in fluid communication with fractures generally aligned along with the minor direction of fluid permeability and initiating combustion in the oil shale adjacent such wells,

(e) driving a combustion front through the oil shale in a direction generally aligned with the major direction of fluid permeability to effect retorting of shale oil products, and

(f) recovering the shale oil products from the wells generally aligned along with the major direction of fluid permeability from the wells used for supplying the heat-creating gas.

3. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to locate sufficient natural fractures to determine the regional fracture trend and the interconnecting natural fractures disposed in other horizontal directions,

(b) determining the major and minor directions of fluid permeability of the oil shale,

(c) providing a plurality of injection wells in communication with a natural fracture generally disposed along with the minor direction of fluid permeability,

(d) providing a plurality of production wells, each production well generally disposed in alignment with the major direction of fluid permeability from an injection well in communication with at least one natural fracture aligned with the regional fracture trend,

(e) supplying a heat-creating gas through the injection wells and initiating combustion in the oil shale adjacent such wells,

(f) driving a combustion front through the fractures providing fluid communication between the injection and production wells to effect retorting of shale oil products, and

(g) recovering shale oil products from the production wells.

4. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to determine the disposition of natural fractures in horizontal directions,

(b) determining the major and minor directions of fluid permeability of the oil shale,

(c) providing a plurality of horizontally spaced injection wells, each well in communication with at least one natural fracture generally disposed along with the minor direction of fluid permeability, said wells spaced at a distance representing the maximum distance between adjacent fractures in substantially all of the fractures surveyed,

(d) providing a plurality of production wells, each well generally disposed in alignment with the major direction of fluid permeability from an injection well in communication with at least one natural fracture disposed in the same general horizontal direction,

(e) supplying a heat-creating gas through the injection wells and initiating combustion in the oil shale adjacent such wells,

(f) driving a combustion front through oil shale along the fractures providing communication between the injection and production wells to effect retorting of shale oil products, and

(g) recovering shale oil products from the production wells.

5. The method of claim 4 wherein the injection wells are spaced a distance apart of about 12 feet.

6. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to determine the disposition of natural fractures in horizontal directions,

(b) providing a plurality of wells distributed throughout the oil shale formation to be retorted and said wells being in communication with the natural fractures,

(c) injecting a tracer gas through one of said wells and venting the remainder of said wells,

(d) pressuring the tracer gas through the natural fractures with a tracer-free gas,

(e) monitoring the gaseous effluent of each of the vented wells for the tracer gas, the wells for a given spacing from the injection well producing the predominant indicia of tracer gas in their effluent gases residing in a direction of the major fluid permeability of the oil shale from the injection well, and the remaining wells producing the least indicia of tracer gas in their effluent gases residing in a direction of the minor fluid permeability from the injection well,

(f) supplying a heat-creating gas through some of the wells generally aligned along the minor direction of fluid permeability and initiating combustion in the oil shale adjacent some of the wells generally aligned along the minor direction of fluid permeability,

(g) driving a combustion front through the oil shale between the wells generally aligned along with the minor direction of fluid permeability to the wells generally aligned along with the major direction of fluid permeability to effect retorting of shale oil products, and

(h) recovering the shale oil products from the wells generally aligned along the major direction of fluid permeability.

7. The method of claim 6 wherein the tracer gas is Freon-12.

8. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to determine the disposition of natural fractures in horizontal directions,

(b) establishing fluid communication with a plurality of the natural fractures in the oil shale to be retorted,

(c) injecting a pressured fluid into the fractures in at least one location in the oil shale,

(d) measuring the amount of fluid passing through the fractures in several divergent horizontal directions from the location of injection under substantially identical fluid measuring conditions, the greatest quantity of pressured fluid flowing in alignment with the major direction of fluid permeability of the oil shale and the lesser quantity of fluid flowing in alignment with the minor direction of fluid permeability,

(e) establishing a combustion front in the oil shale which extends thereacross in general alignment with the minor direction of fluid permeability,

(f) driving the combustion front in a direction in general alignment along with the major direction of fluid permeability to effect retorting of shale oil products, and

(g) recovering the shale oil products from oil shale.

9. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to locate sufficient natural vertical fractures to determine the regional fracture trend and the disposition in other horizontal directions of interconnecting fractures,

(b) determining the major and minor directions of fluid permeability of the oil shale,

(c) establishing a combustion front in the oil shale which extends thereacross in general alignment with the minor direction of fluid permeability,

(d) driving the combustion front through the oil shale in a direction in general alignment with the major direction of fluid permeability toward a means for recovering shale oil products, which means is in fluid communication with a natural vertical fracture aligned with the regional fracture trend to effect retorting of shale oil products, and

(e) recovering the shale oil products from the oil shale.

10. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to locate sufficient natural fractures to determine the regional fracture trend and the disposition in other horizontal directions of interconnecting fractures,

(b) determining the major and minor directions of fluid permeability of the oil shale,

(c) placing a plurality of injection wells into fluid communication with at least one fracture which generally extends along with the minor direction of fluid permeability,

(d) placing a plurality of production wells in alignment with the major direction of fluid permeability from each of the injection wells into fluid communication with fractures aligned with the regional fracture trend,

(e) establishing a combustion front in the oil shale which extends thereacross in general alignment with the minor direction of fluid permeability,

(f) supplying a heat-creating gas into the injection wells to drive the combustion front through the oil shale between the injection and production wells in a direction in general alignment with the major direction of fluid permeability to effect retorting of shale oil products, and

(g) recovering the shale oil products from the production wells.

11. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) performing a geological survey of the oil shale to be retorted to locate some of the vertical fractures which are disposed in one general horizontal direction and some of the interconnecting vertical fractures disposed in other horizontal directions,

(b) determining the major and minor directions of fluid permeability of the oil shale,

(c) placing at least one injection well into fluid communication with an interconnecting vertical fracture disposed in one of said other horizontal directions in general alignment with the minor direction of fluid permeability,

(d) placing at least one production well into fluid communication with a vertical fracture disposed in said one general horizontal direction in general alignment with the major direction of fluid permeability from each of the injection wells,

(e) establishing a combustion front in the oil shale which generally extends thereacross in alignment with the minor direction of fluid permeability,

(f) injecting a heat-creating gas into at least one of the injection wells to drive the combustion front through the oil shale between the injection and production wells in a direction in general alignment with the major direction of fluid permeability to effect retorting of shale oil products, and

(g) recovering the shale oil products from at least one of the production wells.

12. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) passing a combustion front from an injection well to a production well for retorting shale oil products from oil shale wherein said wells are provided fluid communication with the interconnecting natural vertical fractures present in the oil shale and the injection and production wells are in alignment with the major direction of fluid permeability of the oil shale with the production well in fluid communication with a vertical fracture aligned with the regional fracture trend, and

(b) recovering shale oil products from the production well.

13. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) providing a plurality of wells in fluid communication with the interconnected natural vertical fractures present in the oil shale,

(b) supplying a heat-creating gas through a first well an initiating combustion in the oil shale adjacent said well,

(c) driving a combustion front from the first well through the oil shale along the fractures present in the oil shale to a second well in fluid communication with a vertical fracture aligned with the regional fracture trend and disposed in alignment with the major direction of fluid permeability from the first well, and

(d) recovering shale oil products from said second well.

14. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) providing a plurality of wells in fluid communication with the interconnected natural vertical fractures present in oil shale,

(b) supplying a heat-creating gas through several of the wells in alignment with the minor direction of fluid permeability and initiating combustion in the oil shale adjacent such wells,

(c) driving a combustion front from the wells supplying the heat-creating gas through the oil shale to several wells adapted for recovering shale oil products in fluid communication with a vertical fracture aligned with the regional fracture trend and disposed from the heat-creating gas supplying wells in a direction in alignment with the major direction of fluid permeability, and

(d) recovering shale oil products from the shale oil products recovering wells.

15. A method for in situ combustion of oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction, comprising the steps of:

(a) passing a combustion front from a plurality of injection wells in fluid communication with vertical fractures other than ones aligned with the major direction of fluid permeability to a plurality of production wells in fluid communication with vertical fractures aligned with the regional fracture trend and the production wells disposed from the injection wells in alignment with the major direction of fluid permeability in the oil shale, and

(b) recovering shale oil products from the production wells.

16. A structure for producing shale oil products comprising:

(a) an oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction,

(b) a plurality of means for conveying fluids meeting in fluid communication with the vertical fractures at spaced-apart locations in the oil shale,

(c) one of said means meeting with a vertical fracture aligned with the regional fracture trend and oriented from other of the means on a line in substantial alignment with the major direction of fluid permeability in the oil shale,

(d) means for supplying a heat-creating gas into the oil shale connected with one of said means for conveying fluids, and

(e) means for removing shale oil products from the oil shale to the surface of the earth connected with other of said means for conveying fluids.

17. A structure for producing shale oil products comprising:

(a) an oil shale having interconnected fractures, which fractures are oriented predominantly vertically and aligned in the majority along a regional fracture trend, and a predominant fluid permeability in one direction,

(b) a plurality of means for conveying fluids meeting in fluid communication with the vertical fractures at spaced-apart locations in the oil shale,

(c) some of said means aligned in the minor direction of fluid permeability,

(d) means for supplying a heat-creating gas into the oil shale connected with said means for conveying fluids aligned in the minor direction of fluid permeability in the oil shale,

(e) other of said means for conveying fluids meeting with fractures aligned with the regional fracture trend and disposed in the oil shale in substantial alignment with the major direction of fluid permeability of the oil shale from the means for conveying fluids of the element (c), and

(f) means for removing shale oil products from the oil shale to the surface of the earth connected with the means of element (e).

18. The structure of claim **17** wherein one of the means for conveying fluids in the element (c) meets with a vertical fracture other than one aligned with the direction of the regional fracture trend in the oil shale.

19. The structure of claim **17** wherein one of the means for conveying fluids of the element (c) meets with a vertical fracture other than one aligned with the direction of the regional fracture trend in the oil shale, and the means for conveying fluids of the element (e) are aligned with respect to one another in the minor direction of fluid permeability in the oil shale.

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