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J. H. SMITH

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RECOVERY OF OIL FROM SHALE

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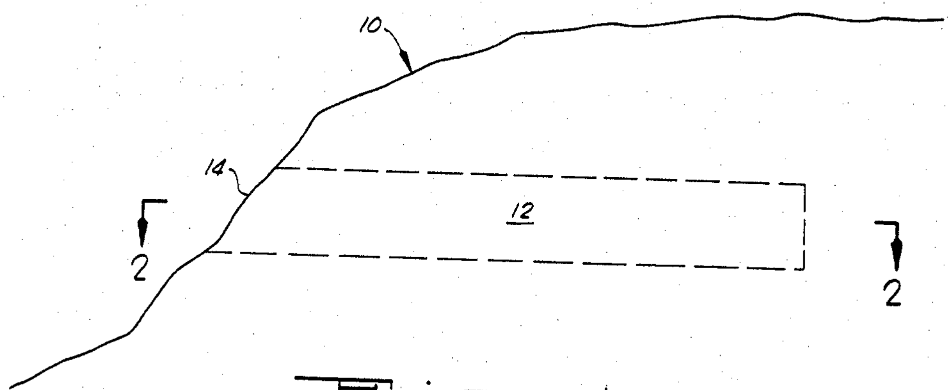

Fig-1

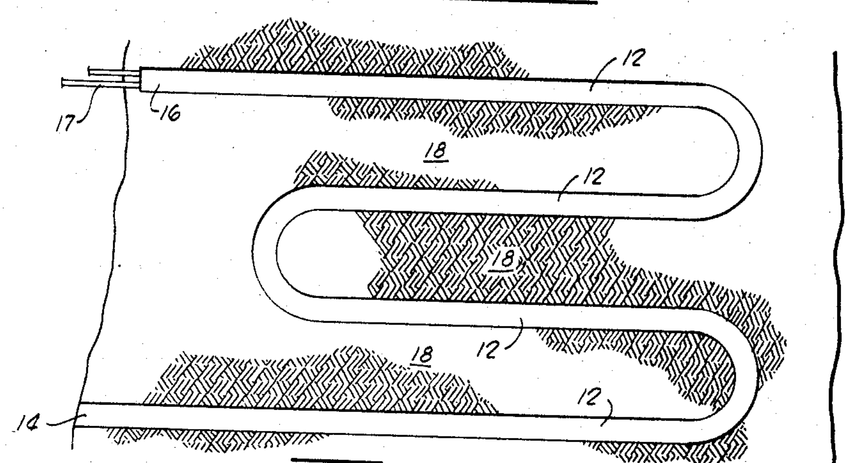

Fig-2

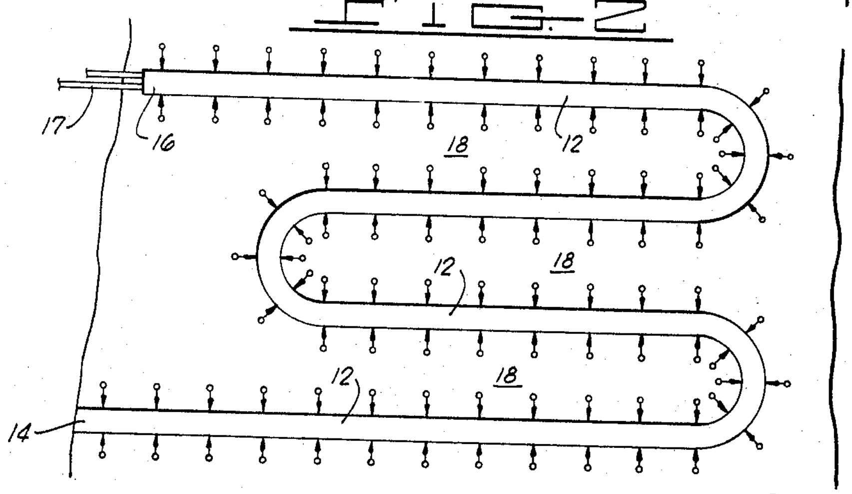

Fig-3

INVENTOR.
JOHN H. SMITH
BY David P. Cullen
ATTORNEY

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RECOVERY OF OIL FROM SHALE

John H. Smith, Ponca City, Okla., assignor to Continental Oil Company, Ponca City, Okla., a corporation of Delaware

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ABSTRACT OF THE DISCLOSURE

A method for recovering petroleum from relatively impermeable, subterranean oil shale deposits more economically than previously known methods. The method of the invention involves the consecutive practice of three basic steps. First, a subterranean tunnel mining procedure is used to form an elongated, serpentine tunnel through the shale strata, with the removed shale being processed by crushing and retorting to recover oil therefrom. Explosives are then detonated in the tunnel to implode the walls and ceiling of the tunnel and fill the tunnel with shale rubble. In the final step of the procedure, in situ combustion is commenced at one end of the tunnel, and the combustion then progressively propagated to the other end of the tunnel to recover a substantial portion of the oil from the rubbleized shale in the tunnel.

BACKGROUND OF THE INVENTION

Field of the invention

The field of technology to which the present invention appertains is that of petroleum production. More specifically, the present invention relates to a method for recovering oil from relatively impermeable oil shales.

Description of the prior art

Numerous procedures have been heretofore proposed for recovering from relatively impermeable oil shales, the great quantities of kerogen derived oil which are retained in these shales. The primary problem has remained that of providing a process which is sufficiently economical in practice to justify its employment in competition with the established, and relatively much more economical, processes which are conventionally used to recover petroleum from other types of substerranean formations having a high degree of permeability.

Among the procedures recently proposed for recovering oil from shale deposits, a few have made use of in situ combustion, a technique now well understood and widely practiced in the secondary recovery of oil from permeable oil bearing formations. In one of these processes, as it is disclosed in U.S. Patent 3,001,775 to Allred, a hole is initially drilled from the surface through the shale formation to the bottom of the formation. A large cavity is next formed at the bottom of the hole by acidizing, fracturing or other suitable means. Explosives are detonated in the cavity to fracture and rubbleize the surrounding shale. Then a well is drilled through the fractured shale to the bottom of the cavity, and finally, in situ combustion is initiated in the rubbleized shale, and the combustion products and displaced hydrocarbon vapors are recovered from the well.

SUMMARY OF THE INVENTION

The invention here disclosed is a method for recovering oil from shale more economically than has been characteristic of previously proposed methods for accomplishing such recovery. The initial recovery of the oil is effected by mining the shale, and then extracting the oil from the recovered rock by any of a number of commonly

used procedures, such as, for example, by crushing it and then subjecting it to retorting. The mining of the shale is carried out in such a way as to form a sinuous passageway or tunnel through the oil bearing strata. The tunnel preferably is serpentine in geometric configuration with parallel legs interconnected by curved portions at the ends of the legs. Upon completion of the tunnel, explosives are detonated in the tunnel to implode the walls and ceiling of the tunnel, and at least partially fill the tunnel with fractured pieces and chunks of the shale.

Following detonation of the explosive charges in the tunnel, combustion of the kerogenic content of the rubbleized shale in the tunnel is commenced at one end of the tunnel, and is propagated toward the other end of the tunnel by any of the in situ combustion techniques now well understood in the technology of petroleum production. The displaced hydrocarbons are recovered at the other end of the tunnel.

In a preferred embodiment of the invention, not more than one-third of the accessible oil shale is removed by tunneling for the purpose of external retorting. Also, the parallel legs of the serpentine tunnel are preferably spaced far enough apart that the intervening long narrow ribs of the shale will remain intact during the explosion and will thus provide support for the overburden, as well as assuring that the combustion gases will follow the course of the tunnel during the in situ combustion.

From the foregoing description of the prior art and the general summary of the invention, it will have become apparent that it is a major object of the invention to improve the economy with which oil can be recovered from kerogen bearing, relatively impermeable shale formations.

Another object of the invention is to economically combine the techniques of external retorting and in situ combustion for the purpose of recovering petroleum from impermeable oil shales.

In addition to these objects and advantages, other objects and advantages will become apparent as the following detailed description is read in conjunction with the accompanying drawings which illustrate the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIGURE 1 is a schematic illustration of the environment of a shale formation in which the method of the present invention is to be practiced. A tunnel excavated in accordance with the method of the invention is illustrated in dashed lines.

FIGURE 2 is a horizontal sectional view taken along line 2—2 of FIGURE 1 to illustrate the sinuous course of the tunnel through the shale formation.

FIGURE 3 is a view similar to FIGURE 2, but schematically indicating the manner in which explosive charges are employed to blast the walls and ceiling of the tunnel to collapse fractured shale into the tunnel.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to the drawings in detail, and particularly to FIGURE 1, for the purpose of better illustrating a preferred embodiment of the invention, a somewhat hilly or mountainous terrain **10** in which a subterranean formation of oil bearing shale may be located is depicted. The drawing may be alternatively considered to depict the wall or face of a gorge or canyon cut by a river, or any escarpment. It will be assumed in discussing the invention that a shale formation is exposed at an outcrop on the side of the hill, and thus is readily accessible to mining by tunneling inwardly through the outcrop in a horizontal direction. This type of mining is generally termed cliff face mining. The generally horizontal tunnel **12** extended into the shale formation is illustrated in dashed lines with the entrance to one end of the tunnel as it is disposed in the shale outcrop being designated by reference numeral **14**. From the opening or entrance **14**, the horizontally extending tunnel **12** is extended for a substantial distance into the wall of the canyon or side of the mountain containing the shale deposit.

A horizontal section taken through the hill **10** in which the tunnel **12** has been excavated is depicted in FIGURE 2 of the drawings. It will be noted that the tunnel **12**, which is excavated as hereinbefore described, is of an elongated sinuous or anfractuous geometric configuration. The tunnel **12** preferably includes a plurality of substantially parallel, elongated legs which are interconnected at their ends through a plurality of curved portions. In the illustrated environment of the tunnel **12**, the tunnel is excavated so as to terminate at a location which is horizontally spaced from the tunnel entrance or opening **14**, with such terminus being designated by reference numeral **16** in FIGURE 2. Discharge pipes **17** are extended from the terminus **16** of the tunnel through the face of the hill **10** for a purpose hereinafter described.

It should be pointed out that, although the foregoing description and the drawings make reference to the formation of the tunnel in a horizontal direction and with openings into the tunnel through outcrops of the shale formation, this precise procedure need not be followed. Where no outcropping of the shale formation occurs, it may be necessary to initially excavate large vertically extending or slanting holes into the shale before commencing the horizontal tunneling. Under some conditions it may also be necessary or desirable to extend the tunnel in one or more planes which depart from the horizontal to a substantial extent. In all instances, it will, of course, be necessary for the tunnel to follow the horizontal contour of the shale formation, and thus, in some instances, the tunnel may slope upwardly over a portion of its length, and downwardly at other locations. It is preferred that the tunnel incline slightly downwardly with respect to the horizontal near its closed end or terminus **16**.

While substantially any conventional mining technique can be utilized in the formation of the tunnel **12** through the shale formation, several considerations as to the geometry of the tunnel, and the amount of shale displaced from the tunnel, are important in the practice of the invention. Thus, it is preferred that the elongated, substantially parallel legs of the tunnel be spaced a sufficient horizontal distance from each other that during the blasting or imploding step of the process which is subsequently carried out (and hereinafter described), a sufficient amount of the shale material **18** which is located between the legs of the tunnel will be left intact and unfractured. This intervening shale material **18** provides support for the overburden, and also prevents by-passing of combustion gases between the elongated parallel legs of the tunnel at such time as the in-situ combustion step of the process is carried out as hereinafter described. In general, a distance of from about 40 feet to about 90 feet should separate the parallel legs of the tunnel **12** prior to the blasting step hereinafter described. A separation of about 60 feet will usually be preferred for most types of oil bearing shale formations in which the method of the invention will be carried out. In any specific instance, however, the actual and exact distance selected will depend upon several variable factors, including the natural permeability of the shale, the depth of the tunnel as such affects the weight of the overburden, and the size and type of explosive to be used to implode the shale adjacent the tunnel.

A second consideration which is of significance in the practice of the invention in the preferred manner is the total length and diametric size of the tunnel **12**. In general, it is desirable to remove as little of the shale by the mining procedure as it is possible to remove and yet provide a tunnel of a size and shape which will give the maximum amount of exposure to the maximum amount of rubbleized shale during the in-situ combustion step subsequently carried out. The tunnel must, of course, be large enough in width and height to permit the mining equipment to advance, and to permit maneuvering of the elongated drills necessary to form drill holes for the accommodation of explosive charges. As to the length of the tunnel, it is preferred that the tunnel be extended to the greatest length possible, since the thermal efficiency realized in the in-situ combustion of the rubbleized shale increases as the total length of the tunnel increases. When these factors are collectively considered, it will be perceived that the tunnel may be of any convenient width, but will generally not need to exceed 60 feet in width to accommodate any type of mining and drilling equipment now in use. In most instances, a width of from about 10 to about 25 feet will be adequate. The height need be no greater than necessary for efficient mining or to permit drilling into the ceiling for implosion thereof to the limit of the rich oil-bearing strata. In different terms, the mining operation will generally be carried out so as to remove from about 15 volume percent to about 50 volume percent of the total shale present in the formation, with the preferred practice resulting in the removal of not more than about 33 volume percent of the shale. This limitation assures that an amount of shale will not be removed from the formation by the mining procedure which is in excess of that required to provide a favorable economical balance between the retorting and in situ combustion oil recovery steps which are conjunctively involved in the practice of the invention.

As oil bearing shale is removed from the shale formation by the tunneling procedure described, the removed shale is treated to recover shale oil therefrom. In a preferred technique of treatment, the shale is crushed by any suitable crushing apparatus, and is subjected to a retorting procedure for extracting the oil therefrom. Crushing and retorting of oil bearing shale for this purpose is well understood in the art, such practice being variously described in the art as the U.S. Bureau of Mines Gas Combustion process, the Tosco process, and the Union Oil Co. reverse flow process. Reference may be made to U.S. Bureau of Mines Bulletin 611 for information relative to a typical retorting procedure which can be employed.

When the tunnel **12** has been completed in the sinuous or serpentine configuration depicted in FIGURE 2 of the drawings, the next step of the procedure of the present invention involves the implosion of the adjacent shale formation forming the walls and ceiling of the tunnel **12** so as to at least partially fill the tunnel with fractured or rubbleized shale. The implosion of the shale adjacent the tunnel **12** is accomplished by positioning explosive charges in the shale adjacent the tunnel, somewhat as indicated by the small, open dots depicted adjacent the tunnel in FIGURE 3. An explosive material which can be conveniently and economically employed is a mixture of ammonium nitrate and diesel oil now widely used in some types of shale mining operations.

After the explosive charges are positioned adjacent the tunnel **12** in this manner and are oriented so that the blast effect is directional and acts primarily in an inward direction toward the tunnel, the charges are detonated. The directional effect of the explosives which are utilized for imploding the shale is depicted schematically in FIGURE 3 where the arrows are used to indicate the direction in which the force of the explosion acts. The positioning of the explosives and selection of explosive size will be determined by the necessity to maintain the narrow strips **18** of intact shale between the elongated parallel legs of the tunnel **12** while rubbleizing as much of the shale as possible in the most economical manner. Thus, it is undesirable to use charges which are large enough to cause fracturing of the intervening strips **18** of the shale since this would weaken the overburden support, as hereinbefore described, and would also provide some possibility for the combustion gases developed during the in situ combustion step of the process to by-pass or cut across between the parallel legs of the tunnel **12** and thus reduce the efficiency with which an in situ combustion procedure can be utilized to strip vaporized hydrocarbon values from the rubbleized shale deposited in the tunnel over its entire length following the imploding procedure. It is usually desirable that the implosion procedure not reduce the thickness of the intervening shale to less than about 30 feet.

Once the explosive charges have been detonated to rubbleize a large quantity of the shale adjacent the tunnel and deposit this fractured shale in the tunnel, the next step in the practice of the method of the invention entails carrying out in situ combustion in the tunnel **12** to extract from the rubbleized shale therein, a substantial portion of the hydrocarbons entrapped in this material. In situ combustion procedures are now well understood in the petroleum production technology and will not be discussed here in great detail. It may be pointed out, however, that the provision of the tunnel in a hill or a mountain so that its inlet and outlet may be formed through an outcrop eliminates the necessity to drill ignition and production wells as in the case of conventional in situ combustion processes used in recovering oil from many of the more permeable and deeper oil bearing formations.

In a preferred in situ combustion procedure which can be employed in the present invention, combustion will be initiated at the inlet end of the tunnel, following which an oxygen containing gas—such as, a mixture of recycle gas and air or oxygen—will be continuously circulated through the tunnel from inlet to outlet. As the flame front advances through the tunnel, the oxygen containing gas will be preheated by flowing in contact with hot spent shale lying behind the flame front. At the flame front, the oxygen will burn a portion of the combustibles in the recycle gas and/or carbon remaining in the spent shale. The hot gas, now devoid of oxygen, will then surrender heat to the shale beyond the flame front, raising the temperature of said shale sufficiently to decompose the kerogen therein and convert it to shale oil vapors which will commingle with the gas.

As the shale oil-containing gas proceeds through the tunnel, it will be cooled by surrendering heat to the raw shale beyond the advancing retorting zone. This cooling will cause essentially all of the shale oil vapors to condense, and the liquid shale oil will ultimately be swept to the outlet of the tunnel by the circulating gas. The shale oil will be separated from the circulating gas at the exit end of the tunnel, and a portion of the gas will be commingled with air or oxygen and returned to the inlet end of the tunnel. The net make gas in excess of the amount recycled may be burned nearby to generate steam or power and/or to provide process heat for refining the raw shale oil. The amount of oxygen added to the recycle gas at the tunnel inlet must be sufficient to generate an adequate retorting temperature (about 900° F.) ahead of the flame front. On the other hand, too much oxygen in the circulating gas would cause excessive temperature at the flame front which would cause fusion of shale and closure of pores to gas flow. Preferably, the oxygen content of the circulating gases at the tunnel inlet should be maintained between 3.0 and 7.0 mol percent with 4.0 to 6.0 mol percent being the most desirable working range.

It should be pointed out that, rather than the described direct or forward in situ combustion, the procedure known in the art as reverse in situ combustion can also be employed. In this type of in situ combustion, the combustion front is initiated at one end of the tunnel and is moved toward the other end of the tunnel while, simultaneously with the propagation of the combustion front in this direction, stripping gases are moved in the opposite direction and function to strip the heated and vaporized hydrocarbons from the heated shale behind the combustion front and move them toward the end of the tunnel at which the combustion front originated. Details

of both procedures will be well understood by those skilled in the art.

By the described process, the present invention permits relatively inaccessible kerogen entrapped in impermeable shale deposits to be thermally converted to shale oil and recovered more economically than has heretofore been possible. The advantages of mining and retorting the shale are combined with those which are realized in an in situ combustion process so that the overall economies effected are relatively great.

Although a preferred embodiment of the present invention has been hereinbefore described in detail, it will be understood that many minor departures from the described steps as used in this embodiment of the invention will still require a dependence upon the basic principles of the invention in order to successfully use the method. All such modifications and changes which still depend upon, and require the utilization of, the basic principles herein enunciated are therefore deemed to be circumscribed by the spirit and scope of the invention except as the same may be necessarily limited by the appended claims or reasonable equivalents thereof.

I claim:

1. The method of recovering oil from shale which comprises:

mining the oil shale formation to remove a quantity of shale from the formation and form a serpentine tunnel having horizontally spaced, substantially parallel legs interconnected by curved tunnel portions at the ends thereof therein;

treating the removed quantity of shale to extract oil therefrom;

imploding the shale formation adjacent the tunnel to deposit fractured shale in the tunnel; and

subjecting the fractured shale in the tunnel to in situ combustion to extract oil therefrom.

2. The method defined in claim **1** wherein said mining is carried out to extend the tunnel substantially horizontally in the shale formation.

3. The method defined in claim **1** wherein said removed quantity of shale is treated by crushing the removed shale, and subjecting the crushed shale to retorting to remove oil therefrom.

4. The method defined in claim **1** wherein the shale formation adjacent the tunnel is imploded by placing explosive charges in the shale adjacent the tunnel and detonating said charges.

5. The method defined in claim **4** wherein the size and location of said explosive charges are preselected to permit a portion of the shale formation to remain intact in a location to provide support for the overburden.

6. The method defined in claim **1** wherein said mining is carried out to provide a tunnel open at both its ends, and said in situ combustion is carried out by:

igniting the kerogenic content of the fractured shale adjacent one end of the tunnel; and

propagating a combustion front from said one end of the tunnel toward the other end thereof.

7. The method defined in claim **1** wherein the quantity of shale removed by said mining operation does not exceed one-third of the total oil bearing shale in the formation.

8. The method defined in claim **1** wherein said mining is carried out so that the parallel legs of said serpentine tunnel are spaced horizontally from each other by a distance such that a portion of the shale between parallel legs of the tunnel is not fractured or substantially weakened by the implosion of the shale formation adjacent the tunnel.

9. The method defined in claim **8** wherein the parallel legs of said serpentine tunnel before implosion are spaced from each other by a distance of from about 40 feet to about 90 feet.

10. The method defined in claim **2** wherein an opening to said tunnel is provided through an outcrop of the oil shale at the face of an escarpment.

11. The method defined in claim **10** wherein said tunnel is terminated adjacent the face of said escarpment without opening therethrough;

and wherein said method is further characterized to include the step of extending fluid discharge pipes through the face of the escarpment into the tunnel at the terminus thereof.

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ERNEST R. PURSER, *Primary Examiner.*

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