United States Patent

[11] 3,620,571

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[21] Appl. No. 833,443
[22] Filed June 16, 1969
[45] Patented Nov. 16, 1971

[54] SINGLE-WELL HEATED GAS MINING METHOD AND APPARATUS
13 Claims, 2 Drawing Figs.

[52] U.S. Cl. 299/6, 126/360, 166/57, 166/303
[51] Int. Cl. E21b 43/24, E21c 41/14
[50] Field of Search ..... 299/1, 3, 6; 166/272, 303, 57, 64; 126/360 A

[56] References Cited

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ABSTRACT: A mineral recovery method useful for mining liquefiable minerals, e.g., sulfur, involves the injection of hot gas, preferably with steam, through a series of concentric injection tubes which penetrate to the bottom of the mineral formation, and purging connate water from the vicinity of the tubes penetrating the formation by injection of such hot gas into the formation. The hot gas flow from the lowermost injection port is then stopped and hot gas flow is continued into the formation from upper injection ports, about 3 to 5 feet above the lower ports. The melted mineral collects as a pool in the vicinity of the lower injection ports and is pumped or air-lifted to the surface by conventional means and is maintained in a fused state by the heat of inflowing gas.

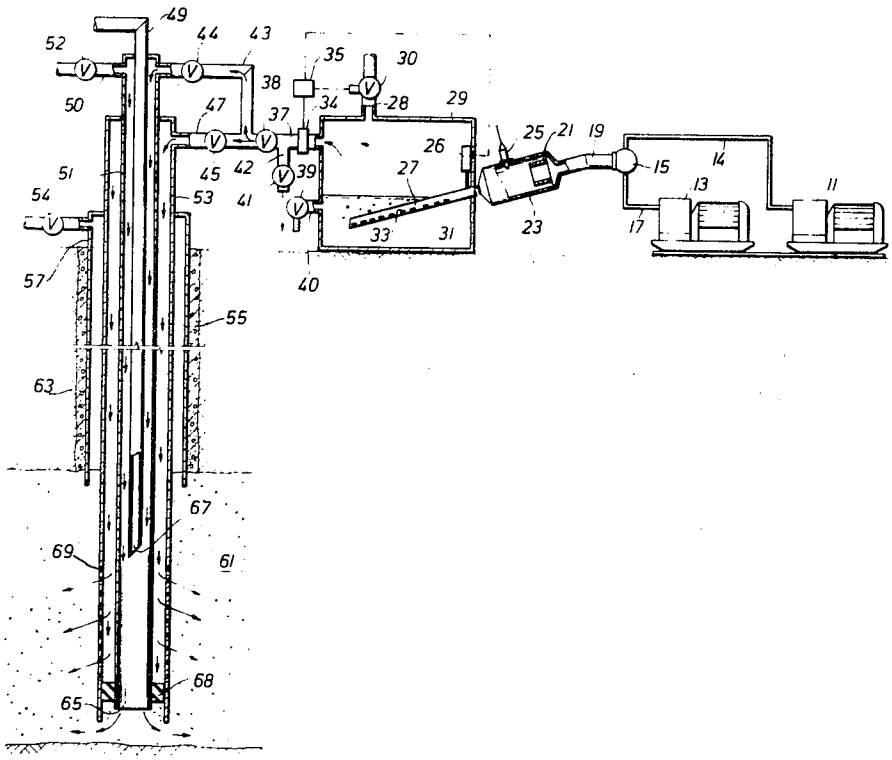


FIG. 1

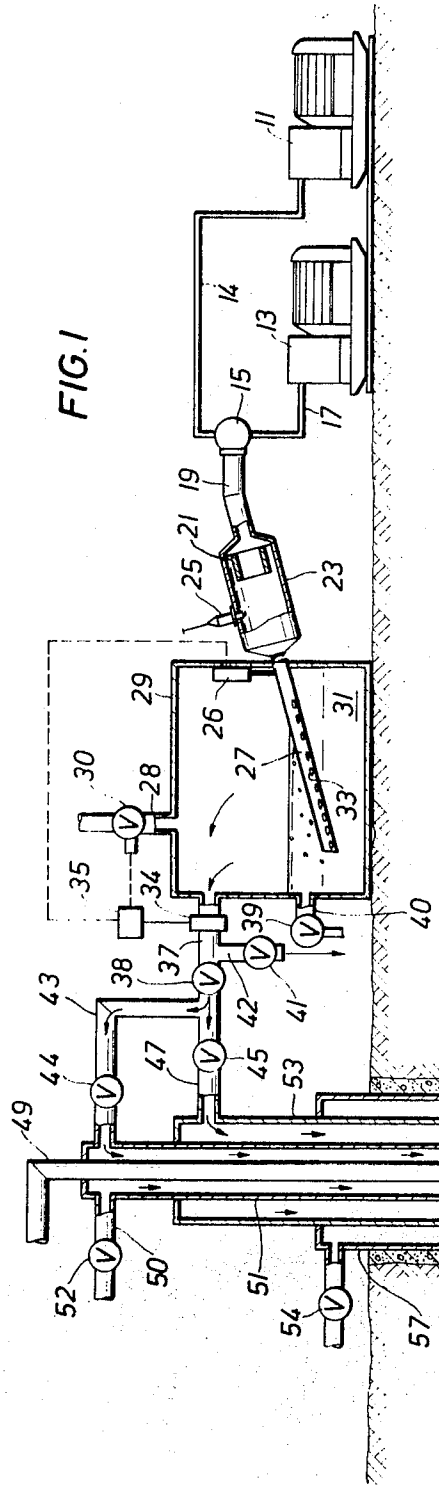
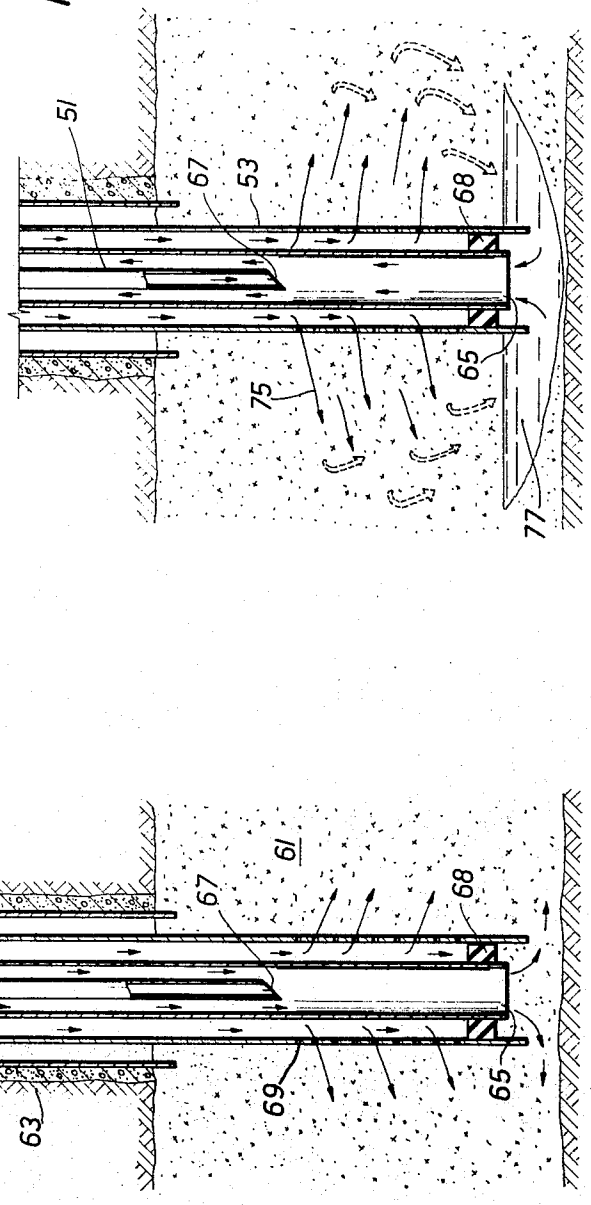


FIG. 2



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SINGLE-WELL HEATED GAS MINING METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

The instant invention relates to a novel method for recovering liquefiable minerals, e.g., sulfur or petroleum, from subsurface deposits. More particularly, the instant invention provides a novel single-well method utilizing hot gas, preferable with steam, to recover such minerals from subsurface formations. Apparatus for conduct of the method is also provided.

In about 1890, one Herman Frasch developed a process for recovering sulfur from subterranean deposits by heating vast quantities of water to about 320° F., and pumping this water down deep wells to the sulfur formation. The heated water fused the sulfur in the formation such that the sulfur can be lifted to the surface in the liquid state by conventional methods such as with an airlift.

Despite its undeniable success and widespread use, the Frasch-type process for recovering sulfur by means of hot water injection suffers apparent disadvantages in its requirement of extensive boiler plant facilities and heated water transmission lines. The boiler necessarily is distant from the point of injection of water in the sulfur deposit and sufficient excess heat must be supplied to the water to allow for heat losses during transmission. Since economy of sulfur production is governed largely by heat requirements, large capital expenditures are necessary to carry out the Frasch process.

In attempts to minimize the capital requirements resulting from the heat requirements and fresh water requirements of the Frasch process, other methods have been developed and suggested for the recovery of sulfur. For example, Dubbs in U.S. Pat. No. 531,787 and Lucas et al. in U.S. Pat. 1,259,536 disclose methods of initiating combustion within a sulfur deposit to actually burn the sulfur in situ followed by removal of the products of combustion.

A further postulated problem with prior art processes utilizing heated water including the Frasch process, has been that once injected into a formation containing cooled connate water, the heated water displaces upwardly because of the difference in density when compared with the comparatively cool connate water. Thus the heating pattern in the formation assumes the shape of an inverted cone and the heat is not dissipated to the formation laterally opposite the point of injection. Moreover, in water injection systems, a bleed well is necessary to remove water from the formation as more is added.

Other methods for recovery of sulfur have involved the use of hot gases rather than hot water as the agents liquefy the sulfur in the deposit. Such a hot flue gas method of mining sulfur is disclosed by Prokop et al. in U.S. Pat. No. 2,808,248. However, the Prokop method involves the use of two spaced-apart wells to effect recovery and requires that the flue gas be supplied to one well at a high temperature and that the mineral, sulfur, be eventually produced through the second well.

Such a process involves the difficulty and potential expense of sinking duplicate, identical wells into the formation in order to effect recovery of the subterranean mineral.

Although with respect to the specification, disclosure will be primarily directed to recovery of sulfur, it will be appreciated that the instant invention may be employed to recover other liquefiable minerals such as gilsonite and mercury from subsurface formations. In addition, petroleum deposits which exist as solids, such as shale oil, or as semisolids, such as in tar sands, may be readily made flowable and/or gasified by addition of heat to the formation according to the method of the instant invention.

SUMMARY OF THE INVENTION

Accordingly, the instant invention provides a novel method for mining a heat-liquefiable mineral from a subsurface formation penetrated by a single well which comprises introducing a gas sufficiently heated to provide the desired degree of liquefication of the subsurface mineral to the formation at vertically

spaced points proximate the bottom of the mineral formation deposit, discontinuing the hot gas flow to the lowermost of said vertically spaced points and continuing the hot gas flow to the upper of said points, collecting the liquefiable minerals in the vicinity of the lowermost point through which gas introduction has been discontinued, and retrieving the liquid mineral to the surface from that lowermost point.

The novel method may be conveniently carried out by sinking a well of four concentric tubes. An inner mineral recovery tube penetrates the formation to proximate the bottom of the mineral formation in the deposit. The mineral recovery tube is open at the bottom or is provided with ports proximate the bottom thereof to communicate with the formation. Arranged concentrically about the mineral recovery tube is a gas inject tube which terminates above the mineral recovery tube or is packed off above the mineral recovery tube and is provided with ports spaced vertically above the ports or open end of the mineral recovery tube. Typically the ports on the gas inject tube will be about 3 to about 8 feet above the opening of the mineral recovery tube.

Hot gas is introduced at the desired temperature, e.g., about 240° F. to about 320° F., to the bottom portion of the mineral deposit through both the mineral recovery tube and the gas inject tube at the outset of the process. Subsequently, the hot gas flow is discontinued through the mineral recovery tube. Liquefied sulfur collects in the region of the ports in the mineral recovery tube and is retrieved to the surface. If desired, a pump or an airlift or gaslift may be employed to assist bringing the liquid sulfur to the surface.

The hot gas product employed in the conduct of this invention preferably comprises a gaseous mixture of suitably pressured fuel combustion products combined with steam. Such a hot gas mixture is suitably provided by compressing air and a fuel to be burned, e.g., natural gas or diesel oil, to a sufficient pressure to overcome the formation pressure in the region of the mineral deposit, burning the fuel preferably with excess air to insure complete combustion and exhausting the heated fuel combustion products of the burning operation beneath the surface of a water pool to thereby cool the heated fuel combustion products and to introduce steam thereto. Alternatively, steam can be introduced by exiting the exhaust gases to a spray chamber to vaporize water and provide the steam constituent.

Normally heated combustion products of a pressurized combustion such as will be conducted here would be far too hot to utilize in most subsurface mining operations. The submerged combustion of such products serves not only to cool such products to the vicinity of utilizable temperatures, e.g., 240° F. to 320° F. in the case of sulfur mining, but also manages to provide an ultimate hot gas mixture carrying a great deal of latent heat in the form of steam.

It has been found that by adjusting the depth at which the combustion products exhaust below the level of the water pool into which they are injected, the temperature of the hot-gas-steam mixture can be conveniently controlled.

It is postulated that initially in the novel method of this invention, the steam constituent of the hot gas mixture gives up its heat rather rapidly upon encountering the formation. However, the gas combustion product of the gas mixture injected into the well continues to move laterally through the formation and purge the region which is penetrated by these gases of connate water. Although heated water is believed to tend to rise in a conical fashion as described above, work which has been done in fire-flooding and in situ combustion in subsurface formations indicates that gas which is introduced to subsurface formations tends to travel laterally. As more heat is introduced to the formation, the steam constituent of the hot gas mixture introduced will tend to travel further and heat the formation while the hot gases also introduce heat laterally outwardly from the well and purge connate water from the region of the well. Inasmuch as gases are primarily being introduced to the formation, any pressure problem which develops in the formation can be relieved by venting high-pressure gas from

the formation to the atmosphere through a gas vent sleeve at the injection well.

Accordingly, the instant novel method provides a technique for recovering a liquefiable mineral, typically sulfur, from a subsurface formation which requires the drilling of only one well.

The instant invention further provides a process for the recovery of such minerals wherein the heating and water requirements are greatly reduced.

The instant invention moreover provides a novel method and discloses novel apparatus for recovery of such minerals wherein an efficient method is provided for generating and regulating the temperature of the gas introduced to the formation. Other advantages of the instant invention, such as the elimination of the necessity for bleed wells and the like will become apparent upon a consideration of the following specification and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The instant invention will be better understood by reference to the accompanying drawings which illustrate specific embodiments.

FIG. 1 is a schematic representation of equipment arranged to conduct the novel process of the instant invention including gas generation equipment maintained at the surface, and the arrangement of tubing to effect introduction of hot gas in recovery of sulfur.

FIG. 2 is a schematic illustration of the flow pattern of hot gas and mineral once hot gas flow from the lowermost injection point has been discontinued and recovery of mineral is commenced.

SPECIFIC AND PREFERRED EMBODIMENTS

Referring now to FIG. 1, the gas generation equipment maintained at the surface typically includes an air compressor 11 and a fuel compressor 13, the outlets of which are combined through lines 14 and 17 respectively at a suitable mixer such as T-mixer 15. The mixer can be an integral part of the burner as will be appreciated by those skilled in the art. Typically, fuel compressor 13 is unnecessary if a suitably pressurized source of natural gas, either from a well or from a pipeline is available at the site. The pressure of the fuel and air will vary depending upon the pressure of the formation being mined. This is generally about one p.s.i.g. per 2 feet of depth. In a further modification, if diesel fuel or another suitable liquid fuel is desired to be used, a suitable compressor may be provided proximate the burner and the liquid fuel may be injected and vaporized under pressure directly into the burner as will be appreciated by those skilled in the art.

The air-fuel mixture is transported from T-mixer 15 to burner 21 through line 19. Typically the air-fuel mixture contains an excess of air in order to insure complete combustion of the fuel within the burner.

The air-fuel mixture flows into combustion zone 23 of burner 21 where it is ignited by spark plug 25 or a like ignition device. The hot combustion products of the burning carried out in the burner travel down through jet nozzle 27 and through openings 33 in the end thereof, which openings exhaust the combustion products beneath the surface of a water pool 31 maintained in reservoir 29 or tank which is closed to maintain the pressure of the exhaust gases. It is preferred that jet openings 33 disperse the combustion gas exhaust into fine bubbles as the heated gases move through the water pool in order to create increased surface area between the hot gases and the water for production of steam. It is further preferred that jet nozzle 27 be inserted laterally in the water bath, e.g., on a slight incline, as illustrated, in order that the rising exhaust gases through the water are dispersed and rise through a larger water surface area resulting in more efficient introduction of steam into the hot exhaust gases. The inclined disposition of the burner is preferred with the burner chamber above the water level to prevent gravity flow of water into the chamber. If the burner is merely disposed above the water level and the gas directed below the water surface by an elbow in a line, the heat of the gases tends to burn out the elbow. Hence a straight exhaust channel is preferred, although other arrangements may be utilized. This has been found more efficient than vertical submersion of the exhaust jet.

It will also be appreciated that other techniques can be employed to introduce the steam constituent to the hot gas mixture. For example, a spray chamber can be employed wherein water is sprayed into the hot combustion product. But this technique is less preferred since the high temperature will affect spray nozzle efficiency, and since it becomes difficult to handle the large volumes of water by spraying alone.

Normally fresh or salt water can be employed in the method of this invention. Chemical additives to control corrosion or for treatment of the formation, particularly petroleum-bearing formations, may be provided in the water.

Temperature of the hot-gas-steam mixture exiting from reservoir 29 may be controlled in a number of ways. If desired, a temperature sensor 34, such as a thermocouple is placed in line 37 through which the hot-gas-steam mixture leaves the reservoir 29. Sensor 34 is provided with a controller 35, such as a pneumatic or electrical controller which regulates the flow of inlet water through water inlet valve 30 and line 28 to the reservoir 29. The temperature of the exiting hot-gas-steam mixture will depend upon the depth of submersion of the exhaust gases beneath the water surface, hence adjustments of water level affect temperature.

Alternatively once the apparatus has reached a steady state of operation, a water level control 26 can be provided to communicate with controller 35 to regulate the inlet flow of water. Desirably a constant blowdown or circulation of water is maintained through reservoir 29 to minimize scaling problems. Thus, there is usually a constant flow through inlet line 28 and through drain line 40, the latter controlled by valve 39. Valve 39 may also be controlled by controller 35, though it is sufficient in most instances to use hand control valve 39 in response to the desired circulation rate.

A pressure regulator valve 38 may be provided in line 37 to control the pressure in the system.

Vent line 42 operated by valve 41 serves to vent the hot gas mixture to the atmosphere to relieve pressure in the system in the event of difficulties with equipment or subsurface formation problems.

Referring now to the tubing arrangement in the well as illustrated in FIG. 1, an outer gas vent tube 57 extends through the overburdening formations 63 to the top portion of the formation 61 containing the mineral, such as sulfur, to be recovered. Gas vent tube 57 is cemented in place as illustrated at 55 and is provided with a suitable gas bleed valve 54 to relieve any pressure buildup which might occur in the formation during conduct of the process. Within tubing 57 is mounted concentrically gas inject tube 53 which extends down to the lower portion of formation 61. The gas inject volume in gas inject tube 53 is the annular space defined by product recovery tube 51 which will be discussed hereinbelow.

Proximate the lower end of gas inject tube 53, ports 69 permit gas flow from gas inject tube 53 to the formation at a point spaced from the bottom of formation 61. Packers 68 seal the annular space between gas inject tube 53 and product recovery tube 51 below ports 69.

Gas inject tube 53 communicates with line 37 carrying the hot gas mixture from reservoir 29 through line 47 and valve 45 by which the flow of gas may be regulated.

Product recovery tube 51 is disposed concentrically within gas inject tube 53 and extends downwardly past packer 68 terminating in open end 65. If desired, product recovery tube 51 can be suitably terminated with a series of ports such as are provided on the gas inject tube. Product recovery tube 51 communicates with gas generated in reservoir 29 through lines 43 and valve 44 which controls the flow. Similarly, product recovery from product recovery tube 51, which will be discussed below, is effected through line 50 controlled by valve 52.

Central line 49 may be optionally provided in the novel method of this invention and customarily is used for injection of air or gas for lift purposes when recovering the mineral through line 51. Preferably, the gas used for airlift through line 49 does not include steam or heated liquid.

Preferably in arranging the tubing in accordance with this invention, product recovery tube 51 is arranged with its lower end or ports 65 proximate the very bottom of formation 61, preferably less than 2 feet. Ports 69 in gas inject tube 53 are spaced vertically above the opening 65 or ports in line 51 by a distance of several feet, usually less than 10 feet.

Accordingly, in operation of the instant novel method, hot gas generated in burner 21 and supplied with steam through submerged jet 27 is initially admitted to both gas inject tube 53 and product recovery tube 51 by opening valves 45 and 44 respectively. At this point, valve 52 on product recovery line 50 is maintained in the closed position.

Thus initially hot gas travels into the formation and exits through ports 69 and through opening or port 65 into the lower portion of the formation as indicated by the arrows in FIG. 1. Preferably, in the case of sulfur mining, these gases are introduced into the formation at a temperature between 240° and 320° F. At temperatures below this range, sulfur will not fuse, while above 320° F. the fused sulfur turns to a more viscous form and flows only difficulty In cases of petroleum mining in shales or tar sands, temperatures between 200° F. and 500° F. may be used, depending on the precise nature of the shale or sands.

In sulfur mining operations, the injection through both gas inject tube 53 and product recovery tube 51 may continue for a matter of hours or a matter of several days until sulfur in the bottom portion of formation 61 is liquefied. The liquid sulfur will flow to the region of greatest heat and consequently will collect in the lower portion of the formation proximate opening of ports 65. When sufficient sulfur has been fused, valve 44 is closed and valve 52 is opened. The sulfur in the formation will rise because of formation pressure in product recovery tube 51 and may be further assisted to the surface by air or gas introduced to the formation through lift line 49. In its travel upwardly through product recovery tube 51, the liquefied mineral is maintained in a liquid state as it travels through an annulus between gas inject tube 53 and lift line 49.

Referring now to FIG. 2, there is shown in schematic form the general flow patterns occurring during the recovery operation. The hot-gas-steam mixture continues to enter the formation through ports 69 of gas inject tube 53. The hot gas mixture flows laterally outwardly to the formation as illustrated by the solid arrows. As the hot gas mixture gives up its heat to the formation, the sulfur tends to flow downwardly to the source of the heat in the direction indicated generally by dotted arrows 75. Sulfur collects at the bottom of the formation in the region of opening 65 of product recovery tube 51 and is recovered upwardly through product recovery tube 51.

As the hot gas proceeds outwardly, it purges connate water from the area within dotted arrows 75 and travels laterally from the formation. In doing so, it continues the liquefication of the mineral which continues to flow into the pool formed at the bottom of the formation.

It will be appreciated that intermittently during operation of the instant process, it may be desirable to increase the introduction of heat to the lower portion of the formation, in which case production of sulfur through product recovery tube 51 could be temporarily discontinued and hot gas could be flowed to the very bottom portion of the formation as originally.

The instant invention having now been particularly described, specifically with reference to the illustrated embodiments, it will be apparent to those skilled in the art that certain modifications can be effected in the instant invention without departing from the spirit or scope thereof. For example, rather than using a hot gas mixture of heated combustion products and steam, hot gas alone can be used to introduce heat to the formation. However, this method is not preferred inasmuch as the latent heat of vaporization of steam is not available to be released to the formation and furthermore, since temperature control of the hot gases is a great deal more difficult under such conditions. If hot gas is to be used, however, great excesses of air or recycle gas from the well are mixed with either fuel or the combustion products in order to decrease temperature.

Furthermore, it will be obvious that sulfur recovery need not be by airlift or gaslift means as illustrated, but sulfur retrieval to the surface may be effected by pumps or other well-known means.

What is claim is:

1. A method for mining a heat-liquefiable mineral from a subsurface formation penetrated by a single well which comprises:

introducing a mixture consisting of hot gas, said hot gas comprising heated fuel combustion products and steam, to the formation at vertically spaced points proximate the of said mineral formation deposit in an amount sufficient to liquefy the mineral in the region of such introduction;

discontinuing hot gas flow to the lowermost of said vertically spaced points and continuing hot gas flow to the upper of said points to purge connate water from said formation nd to liquefy mineral above said lowermost point;

collecting said liquefiable mineral in the vicinity of said lowermost point; and

retrieving said liquid mineral to the surface from said lowermost point.

2. A method for mining a heat-liquefiable mineral from a deposit in a subsurface formation penetrated by a single well which comprises:

introducing a mixture consisting essentially of hot gas, said gas comprising heated fuel combustion products and steam, said mixture being at about 240° F. to about 320° F., to the bottom portion of said deposit through two concentric tubes, the inner of said tubes having ports vertically spaced below the ports of the outer of said tubes to liquefy the mineral in the bottom region of said formation;

discontinuing hot gas flow through said inner tube while continuing hot gas flow through the outer of said tubes;

collecting said liquefied mineral in the vicinity of the ports of said inner tube; and

retrieving the liquid mineral to the surface through said inner tube.

3. The method of claim 2 wherein said heat-liquefiable mineral is sulfur

4. The method of claim 3 wherein said hot gas is generated by

compressing air and fuel to a sufficient pressure to overcome the formation pressure in the region from which said liquefiable mineral is to be recovered;

burning said fuel with excess air to insure complete combustion;

exhausting the heated fuel combustion products of such burning operations beneath the surface of a water pool to add steam thereto.

5. The method of claim 4 wherein said heated fuel combustion products are dispersed from longitudinally spaced ports beneath said water surface to permit said dispersed combustion products to rise through a substantial water surface area.

6. The method of claim 4 including the steps of

sensing the temperature of said heated fuel combustion products and said steam; and

adjusting the distance beneath the water level of said water pool at which said heated fuel combustion products are exhausted.

7. The method of claim 6 wherein said adjustment is accomplished by adding or draining water from said water pool.

8. The method of claim 2 including injecting compressed gas to the region of said liquefied mineral to assist retrieval thereof to the surface.

9. Apparatus for recovery of a liquefiable mineral from a subsurface deposit which comprises:

a source of pressurized air and fuel;

means to mix said air and fuel;

burner means to burn said air and fuel under pressure to form heated combustion products;

a water pool;

exhaust means on said burner means defining a series of longitudinally spaced exhaust ports, said exhaust means submerged laterally below the surface of said water pool for exhausting said heated combustion products beneath the surface of said water pool to produce a hot-gas-steam mixture;

concentric inner and outer tube means extending from the surface to proximate the bottom of the mineral deposit to be mined, said inner and outer tube means both communicating with the mineral deposit said inner tube means communicating with said mineral deposit at a level below said outer tube means; and

means to selectively direct flow of said hot-gas-steam mixture to said inner and outer tubes.

10. The apparatus of claim 9 including:

water inlet and outlet means communicating with said water pool to control the depth of submersion of said exhaust means below the water level of said water pool; and

temperature-regulating means for sensing the temperature of said hot-gas-steam mixture and regulating flow through said water inlet and outlet means to adjust the water level in said pool in response to said temperature.

11. The apparatus of claim 9 including:

gaslift tube means extending concentrically within said inner tube means to provide gas to assist retrieval of the liquefied mineral.

12. The apparatus of claim 9 including:

gas vent tube disposed concentrically outside said outer tube means to the upper portion of said mineral deposit; and means to vent excess pressure from said deposit at the surface through said gas vent tube means.

13. The apparatus of claim 9 wherein aid burner means is disposed above the water level of said water pool and including means defining a substantially straight path for said heated combustion products from said burner means to said exhaust means.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,620,571 Dated November 16, 1971

Inventor(s) Calvin H. Billings

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, lines 62 and 63, "semis-olids" should read -- semi-solids --.
Column 5, line 25, "difficulty" should read -- difficultly --;
line 25, after "difficultly" insert -- . --.
Column 6, line 12, "claim" should read -- claimed --;
line 16, after "consisting" insert -- essentially --;
line 18, after second-appearing "the" insert -- bottom --;
line 22, change "nd" to -- and --.
Column 8, line 13, after "tube" insert -- means --;
line 17, change "aid" to -- said --.

Signed and sealed this 23rd day of May 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents