

Jan. 14, 1969

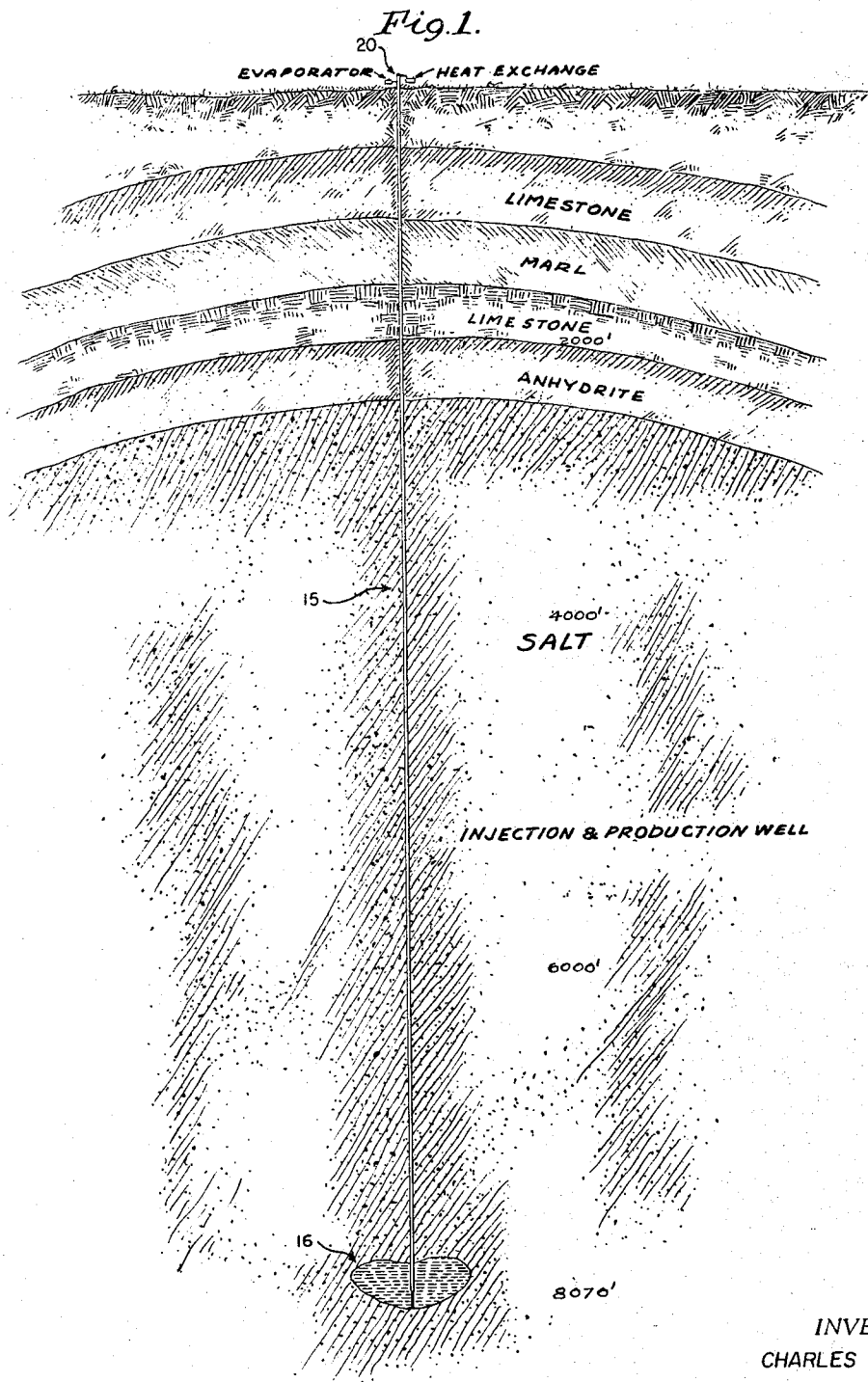
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3,421,794

SOLUTION MINING AND REFINING MINERALS

Filed Sept. 27, 1966

Sheet 1 of 7



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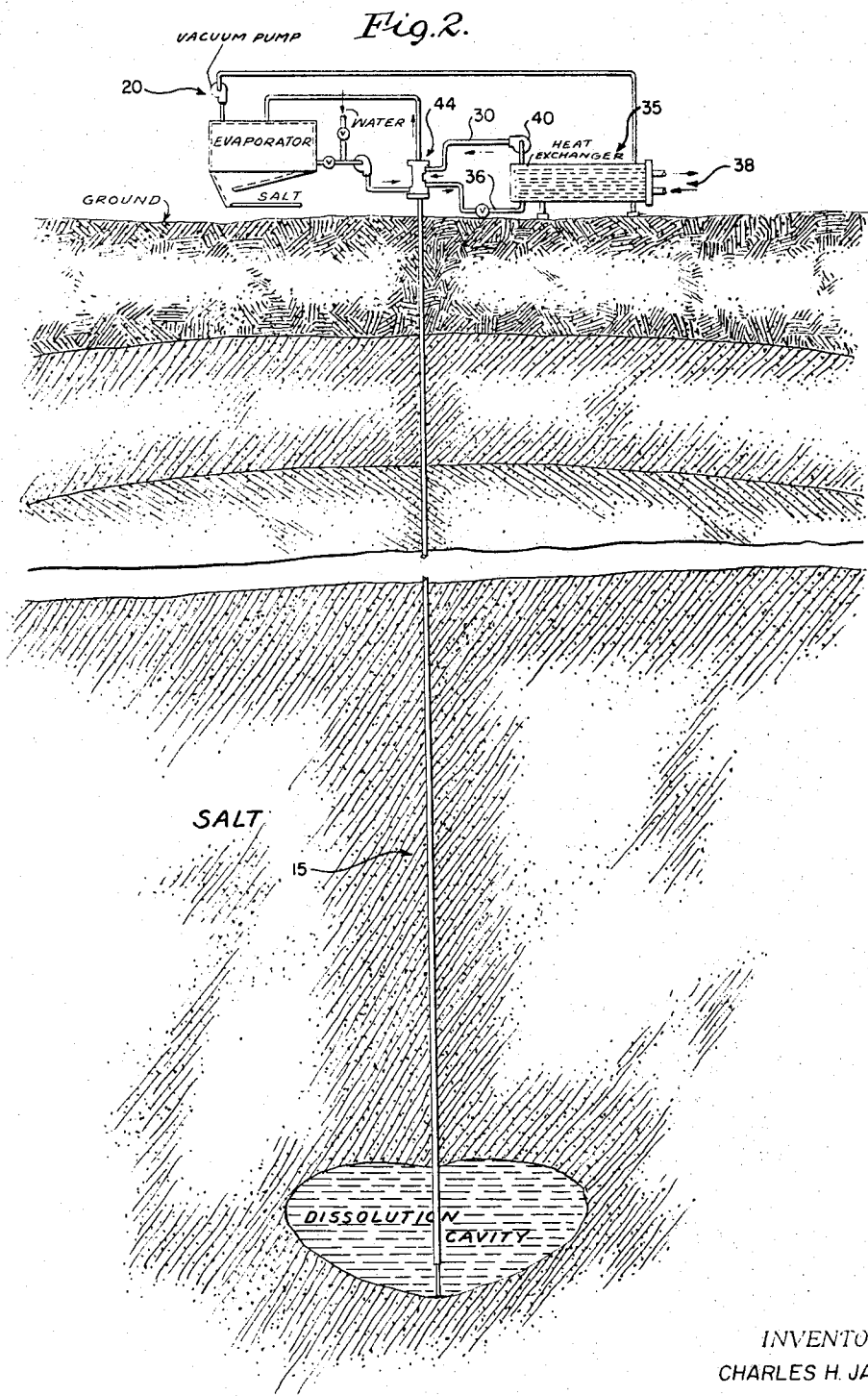
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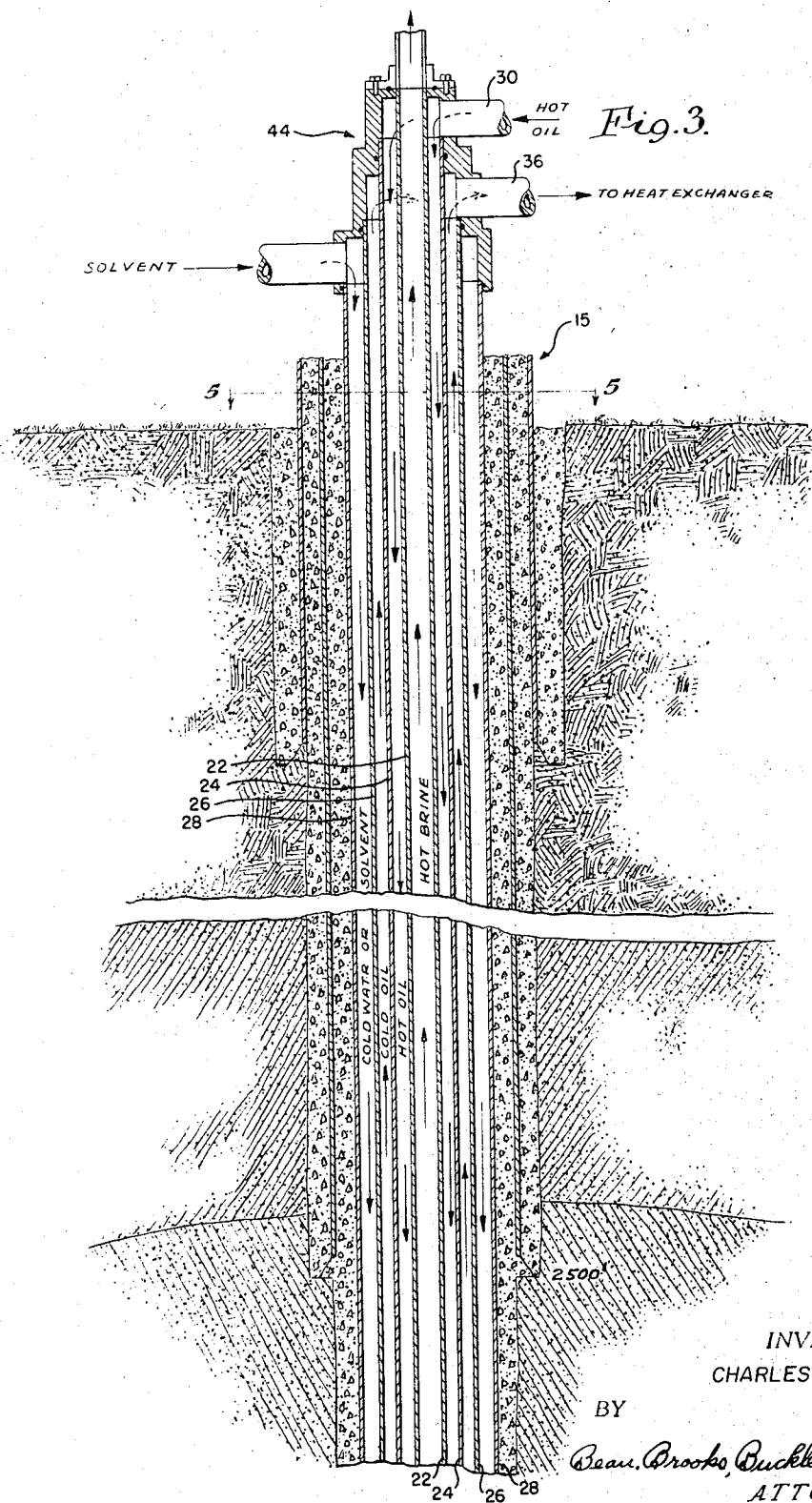
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SOLUTION MINING AND REFINING MINERALS

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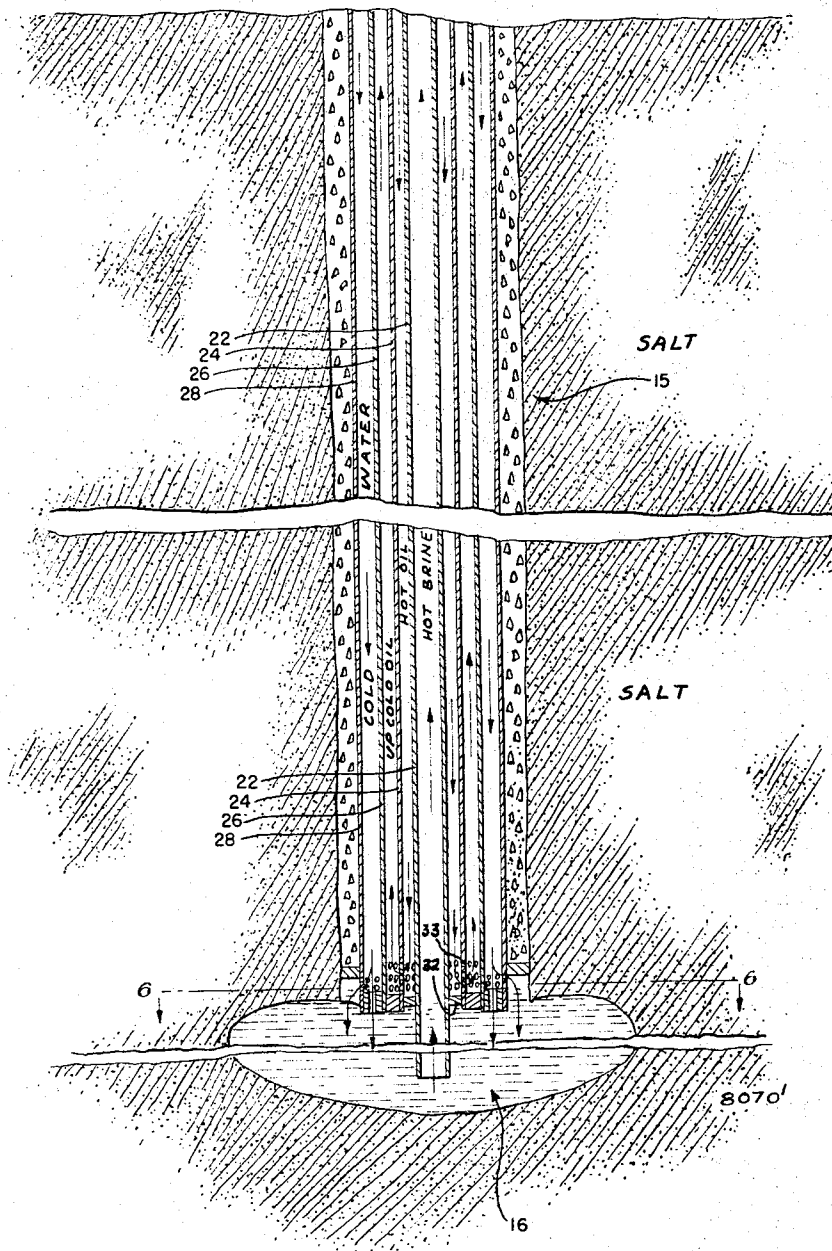
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Fig. 4.



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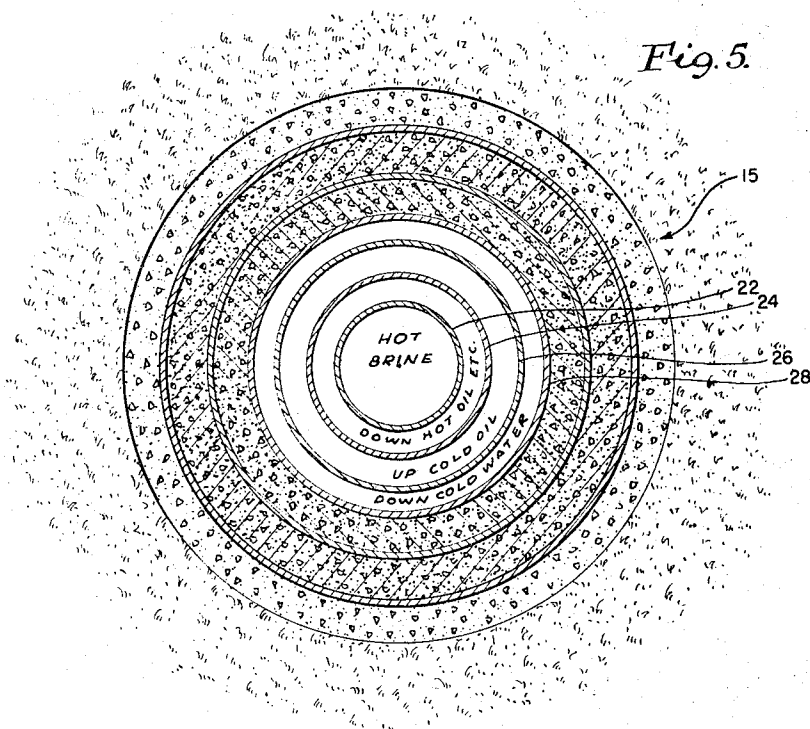
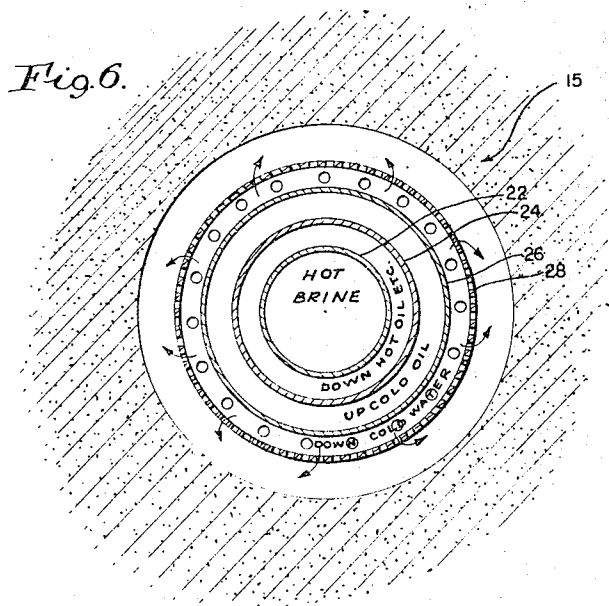
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SOLUTION MINING AND REFINING MINERALS

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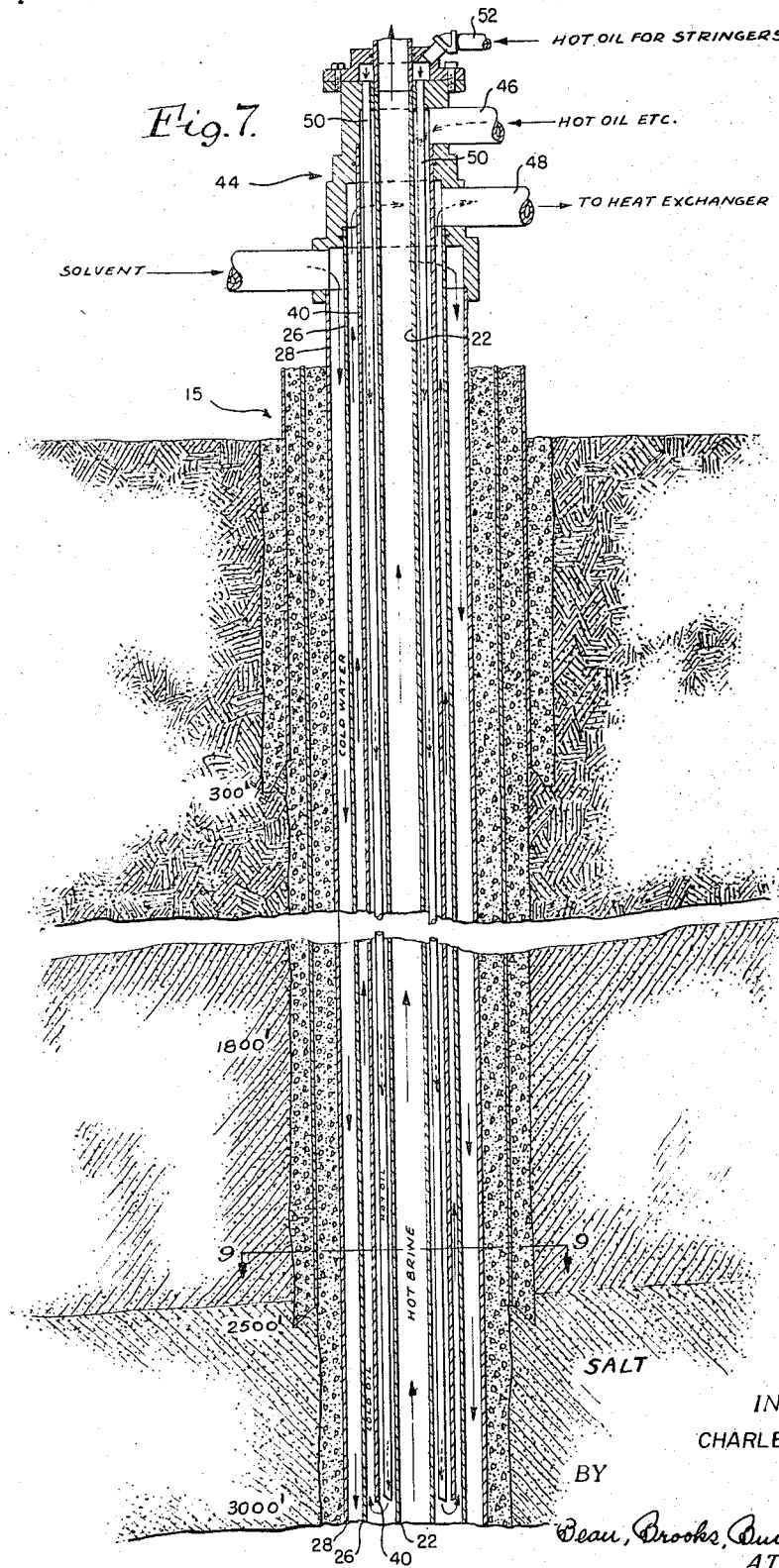
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SOLUTION MINING AND REFINING MINERALS

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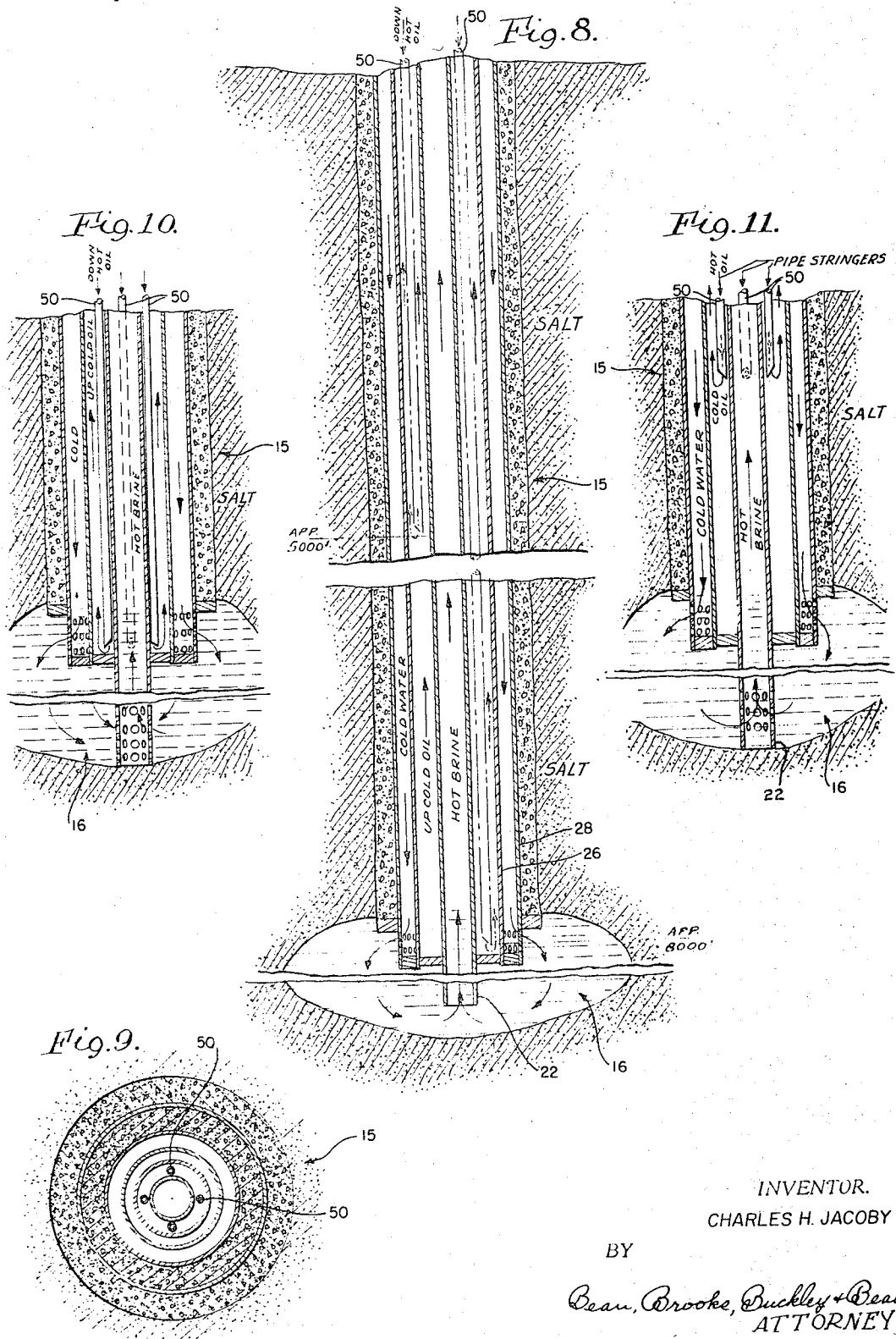
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3,421,794

SOLUTION MINING AND REFINING
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Filed Sept. 27, 1966, Ser. No. 582,352

U.S. Cl. 299—5

17 Claims

Int. Cl. E21b 43/28; E21c 41/08

ABSTRACT OF THE DISCLOSURE

Some of the heat extracted at the earth's surface incidental to winning crystallized mineral from a high temperature saturated mineral solution obtained by flowing solvent through a mineral deposit at great depth is used to (a) minimize temperature drop of the up-coming solution and (b) reduce the rate at which heat is extracted from the deposit.

This invention relates to the mining and refining of soluble minerals; and more particularly to the mining of sodium chloride or other soluble mineral salts including impurities; the absolute and relative solubilities of which vary with temperature and/or pressure changes. More specifically, the invention relates to a process somewhat similar to that disclosed in commonly assigned U.S. patent application Ser. No. 516,621, filed Dec. 27, 1965, now Patent No. 3,348,883 and presently pending in the names of Charles H. Jacoby and John L. Ryon, Jr.

The present invention relates to an improved process and means for refining or "purifying" mineral salts as aforesaid, concomitant to the mining thereof as distinguished for example from the processes disclosed in U.S. Patents Nos. 2,555,340 and 2,876,182. Briefly stated, the prior patented processes involve the taking of raw impure or run-of-mine salt into solution; heating the brine thus formed and making it into a super-saturated salt solution; and then subjecting the solution to evaporating and cooling processes whereby recrystallized, purified, sodium chloride is obtained.

More specifically, as explained in the aforesaid patents, salt such as mined rock salt, usually consists of sodium chloride to the extent of about 90% to 99%; the balance being impurities such as sulphates, silicates, carbonates, etc.; calcium sulphate being the principal impurity. According to prior refining procedures, such "impure" salts have been "refined" in some instances by treatment of saline solutions obtained directly from wells, or from water-solutions produced by dissolving previously mined or otherwise produced impure salt substances in water or other suitable solvents. Then, purified salts have been extracted from such solutions by the use of vacuum-evaporator systems.

In accordance with the aforesaid patents, advantage is taken of the phenomenon known as the "inverse solubility" of calcium sulphate in relation to sodium chloride. The calcium sulphate content of the crude salt which is fed into the system will remain substantially undissolved under certain conditions, and can be removed by filtration or other known methods of separation. In carrying out the system, impure salt is first dissolved in a brine "saturating zone" wherein the temperature and pressure are maintained substantially greater than in the "evaporation" zone. Then when the brine is delivered into the evaporation zone a drop in temperature takes place, with the result that the brine becomes or remains undersaturated with respect to the calcium sulphate even though the concentration of the sodium chloride becomes substantially increased. Or, alternatively, the purer sodium chloride may be precipitated out of the solution at this stage, in ac-

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cordance with the preferred practice. In such case any undissolved material, whether dirt or other undissolved inclusions such as calcium sulphate, is separated from the brine before the brine is taken into the evaporation or recrystallizing zone, with the result that the sodium chloride becomes separated from such impurities; and, if desired, it can then be precipitated out so as to provide a product of high purity. According to such systems sodium chloride of purities in excess of 99.98% can be produced directly from a source of relatively impure salt such as dirty rock salt.

The invention disclosed in the aforesaid copending application Ser. No. 516,621 provides an improved combination salt mining and purifying method and means, employing only some of the previously patented practices referred to above; whereby certain operating advantages accrue in respect to the mining phase as well as in respect to the product beneficiation phase of the overall operation.

However, it is specifically an object of the present invention to provide still further improvements in operative systems and techniques for such purposes; whereby to realize plant completion investment and operating economies.

Another object is to provide an improved system as aforesaid whereby precise operational control and efficiencies may be realized.

Other objects and advantages of the present invention will be apparent from the following specification and the accompanying drawing wherein:

FIG. 1 illustrates diagrammatically by way of a vertical sectional view, a geological formation including a typical salt "dome" in process of being mined in accordance with the present invention;

FIG. 2 is a fragmentary enlarged scale composite view of portions of FIG. 1, including a diagrammatic illustration of the surface-plant equipment of FIG. 1;

FIGS. 3, 4, are enlarged scale diagrammatic illustrations of typical well completion apparatus such as may be employed in conjunction with the production well casing head and foot sections respectively; in accordance with the system of the invention;

FIGS. 5, 6, are enlarged scale sectional views taken as suggested by lines 5—5 and 6—6 respectively of FIGS. 3, 4;

FIGS. 7, 8, are views corresponding to FIGS. 3, 4, but showing a modified form of well completion arrangement such as may be employed in conjunction with the invention;

FIG. 9 is a sectional view taken as suggested by line 9—9 of FIG. 7; and

FIGS. 10, 11, are views corresponding to the bottom end portion of FIG. 8 but showing modified forms of suitable well completion arrangements.

As shown by way of example herein, the invention is embodied in a system for simultaneously mining and "purifying" sodium chloride salt occurring in an underground deposit of the well known "salt dome" type; but it is to be understood that the invention may be usefully applied to other forms of soluble mineral deposits, such as sodium borate, potash, and the like. However, it is a feature of the invention that the system thereof is particularly adapted for use in connection with mineral deposits occurring at relatively great depths below the earth surface, employing as an incident thereto the ambient heat supply inherently existent at deep levels underground. For example, it is known that underground temperatures invariably increase with depth, and that in deep lying salt domes for example, temperatures of the order of 240° F. have been recorded at depths of the order of 8,000 feet.

The present invention takes advantage of the fact that

deposits of salt such as illustrated herein are at such depths that the earth temperatures ambient to a borehole leading downwardly from the surface and penetrating such a deposit are of high order, and may furnish some of the heat supply requirements for a coincident beneficiation operation when employing apparatus of the present invention. Hence, substantial operating economies are effected.

By way of more specific explanation, as illustrated herein in a salt dome or other such deposit may for example be intersected by a vertical borehole as indicated generally at 15, which comprises a combination "injection" and "production" well opening from the earth's surface into the sought-for mineral deposit. To "complete" the borehole and to prevent compression failures of the walls thereof, it will of course be preferably "cased" as is well known in the art. As shown in FIGS. 3-7 the borehole 15 is fitted with a casing system of the concentric quadruple casing type, for purposes to be explained more fully hereinafter. As shown in FIGS. 8, 10, 11, a triple casing system is shown. In any case the borehole is drilled into the salt deposit so that at its nether or lower end it penetrates into the deposit. The multiple casing system of the borehole thus provides a system wherein solvent may be pumped down one of the casing annuli and brine delivered upwardly through another to the surface plant. As is well known in the art, a dissolution cavity as illustrated at 16 for example in FIGS. 1, 2, 4, 8, 10, 11, will thereupon form in the salt deposit, from which saturated brine may be continuously pumped to the surface plant which is indicated generally at 20 (FIGS. 1, 2).

It is a particular feature of the present invention that the system thereof utilizes the vast heat supplies existent at substantial depths in the earth's crust, to assist in the requisite vaporization and/or brine-evaporation phases of the salt product beneficiation operation; and in addition to heat the solvent (comprising the residual brine effluent from the evaporation operation plus make-up fresh solvent added if and when needed) as it is injected through the borehole casing into the dissolution cavity, thereby causing it to be delivered into the cavity in under-saturated condition. By circulating this under-saturated solvent mixture into the dissolution cavity and from thence back to the surface and then through the salt recovery facility, under the specifically controlled conditions of the present invention as will be explained hereinafter, the salt deposit per se provides at the same time the source of raw mineral and a source of a portion of the heat supply which is required in connection with the purification process at the surface plant. When the system is installed and operated within the specific parameters of the present invention, the heat so derived will be so conserved and utilized as to render the system in every way practicable; the abstraction of heat from the salt deposit being automatically compensated by continuous heat conduction replacements from the ambient geology.

As mentioned hereinabove, the casing portion of the system as illustrated at FIGS. 3-7 is of the quadruple casing type; illustrated herein as including concentrically arranged casings of tubings 22, 24, 26, 28. The primary (inner) conduit or tube 22 is provided to convey the product brine in heat-insulated form upwardly to the point of discharge of the brine into the evaporator portion of the brine treating apparatus. The present invention features an arrangement whereby the heated, saturated, brine derived from the dissolution cavity will be maintained under optimum pressure and temperature conditions until delivery to the "evaporator"; thereby preventing premature crystallization of solids in the conduit system.

To accomplish this purpose of this invention a closed-circuit type heat-exchange system is arranged in conjunction with the production brine casing 22. As best shown in FIGS. 3-6, the brine up-flow conduit 22 and the next outer conduit 24 provide therebetween an annular passageway into which heated water, or oil, or sulphur, or other

suitably fluid heat-conveying media may be injected, as from an inlet connection illustrated at 30 (FIG. 3), at the "well head" component of the well. The casing 24 is "packed" at its bottom end as indicated at 32 (FIG. 4) and perforated thereabove as shown at 33. The annular space between the conduits 24 and 26 is arranged to provide a return passageway for the heating fluid on its way back up to the heater 35 (FIG. 2). An exit connection 36 (FIG. 3) is provided at the well head in conjunction with the casing 26 to convey the "return" fluid to the heating apparatus.

The heater 35 may be of any suitable type commercially available heat exchanger employing any preferred form of heat energy source; such as steam from a stand-by-boiler or the like as indicated at 38. Also, the hot vapors effluent from the evaporator operation may be fed to the heater apparatus as illustrated at FIG. 2, to effect heat supply cost economies.

In any case, it is a particular feature of the present invention that the fluid heated by means of the apparatus 35 is circulated as by means of a pump 40 through a closed-circuit system comprising essentially the annular spaces between the well casings 22-24 and 24-26. Therefore the circulating fluid may be selected to provide certain preferred operative characteristics, such as being non-corrosive to the hardware coming in contact therewith, and/or free from precipitant-prone ingredients such as would otherwise tend to "scale" the casing walls or other hardware. Hence substantial maintenance difficulties and expense are avoided.

It is to be understood that the system of the invention may employ any preferred form of salt extracting apparatus. For example, as shown in FIG. 2 herewith it may be of a relatively simple, single stage, "evaporator" or "recrystallizer" type employing procedures disclosed for example in U.S. Patents 2,555,340 and 2,876,182 wherein the brine is subjected to pressure and temperature drop conditions permitting pure solid salt to separate out from the brine. However it is to be understood that in lieu of the simple, basic form of extracting system as suggested by FIG. 2 herewith, any other preferred multi-stage and/or more sophisticated recovery and/or refinery system (such as disclosed in the aforesaid patents) may be employed.

In any case, the effluent residual brine from the recovery facility will preferably be pumped back down the borehole through the annular space defined by the casings 26-28. This brine will be sodium chloride saturated at its injection temperature (except perhaps whenever evaporation losses require the addition of "make-up" solvent which may be furnished at somewhat lower temperature). However, as explained hereinabove, as this brine travels downwardly through the uninsulated casing 28 in heat-exchange relation therewith, it becomes heated; such as by example from an injection temperature of the order of say 90° F. up to a temperature of the order of 220° F. as it traverses the dissolution cavity; assuming the cavity ambient rock temperature to be of the order of 240° F. Because the brine upflow conduit 22 is maintained a high temperature as explained hereinabove, when the superheated (and therefore supersaturated) brine or other solution reaches the evaporator apparatus it may well be of a temperature in the order of 215° F., or more. The resistance to fluid flow offered by the extended casing structures will of course insure to some extent that the dissolution product is also maintained under high pressure until it is discharged into the evaporator apparatus. However, if preferred, a flow restrictive orifice may be employed at the discharge point to maintain the desired back-pressure on the system. Hence, it will be appreciated that the operative characteristics of the solute heating and saturating phase of the system of the invention bring it well within the realm of feasibility for realization of the objects of the invention as set forth hereinabove.

Another technological feature of the system of the in-

vention resulting in improved performance and economic advantages is that by virtue of the operative relationships of the essential components of the system, there is no essential need for certain accessory devices such as are called for by prior art systems. This derives from the fact that insoluble impurities resident in the deposit being mined, tend to settle out of the brine when released by dissolution of the cavity wall material, and fall into and remain in the bottom of the cavity; and therefore the impurity carry-up into the refining apparatus is minimal. Hence, the need for filtering equipment is minimized, and the need for "purifying" equipment such as saturators, condensers, heaters and the like in connection with the surface plant may be eliminated or at least minimized. Also, because in the case of the present invention the insoluble impurities occurring in the mineral deposit are not brought to the surface, there is no problem at the surface plant with respect to disposal of wastes.

It is also noteworthy that in the case of the present invention the phenomenon known as the "inverse solubility ratios" of sodium chloride and calcium sulphate (the major impurity ingredient of native rock salt) operates within the dissolution cavity of the system. Because the solvent liquid in the cavity is maintained a high temperature it automatically retards dissolution of the undesirable calcium sulphate into the brine. Therefore large percentages of this material when released in situ from the salt deposit will simply settle down into the bottom of the dissolution cavity, thereby reducing the impurity separation load on the surface plant. In fact, by virtue of this feature of the invention the surface refining plant requirements may well be so reduced that only a rudimentary form of solid salt recovery apparatus may be satisfactorily employed.

As shown in FIGS. 7, 8, 9, the conduit system for circulating the heating fluid in heat-exchange relation to the brine delivery conduit may be of the so-called "hanging string" type, instead of the type shown in FIGS. 3-6. In this situation, the casing string 24 of FIGS. 3-6 is replaced by a shorter "hanging string" 40 (FIG. 7) which is supported solely from the well head or "Christmas tree" structure as indicated at 44. A heated fluid is then conveyed from the heat exchanger 35 (FIG. 2) through inlet connection 46 (FIG. 7) to travel down in heating relation around the brine upflow conduit 22 and thence around the open end of the hanging pipe 40 and then returning upwardly to exit through the connection 48 for return to the heat exchanger.

In some situations if more precise brine temperature control may be required, this may be attained by installing supplemental heating fluid supply devices such as hanging tubes 50 (FIGS. 7, 8, 9, 10, 11). These may be arranged to deliver heating fluid as through an inlet connection 52 (FIG. 7), down to such depths (within the annulus defined by the tubes 22, 26) as may be found necessary to establish a uniform temperature jacket around the brine conduit throughout its length, notwithstanding the existence of different temperature conditions and/or different heat conductivity characteristics at different levels of the ambient geology. Hence, the supplement heating tubes may preferably terminate at the same or different elevations, as dictated by the underground conditions encountered. Alternatively, the tubes may so be employed to draw off at any desired elevations the fluid within the annulus, to thereby attain precise temperature control of the system.

FIG. 11 also illustrates another form of well "completion" arrangement wherein the brine upflow conduit 22 is disposed to rest at its bottom end upon the solution cavity floor, or within a previously drilled opening extending downwardly into the solid salt mass comprising the cavity floor. Thus, a substantial portion of the weight of the conduit hardware will be carried by the foot of the structure, thereby relieving the loads on the well head and/or packing devices. Also, this system will operate to

positionally stabilize the lower end of the casing hardware in the solution cavity. Although not illustrated herein, it will of course be understood that either pneumatic or immiscible fluid "pads" may be employed to cover the top surface of the liquid occupying the dissolution cavity; thereby insulating the roof of the cavity against undesirable dissolution. By such means the dimensional progress of the dissolution cavity may be preferentially controlled, as is well known in the art.

It is of course in any case a requisite to practical operation of any system such as disclosed hereinabove that care be taken to insure against premature recrystallization of the solute within the ascending column of hot brine, such as would block up the conduit system and render it inoperative. To prevent this, the ascending brine must be kept throughout its travel within a narrow range of temperatures and pressures. In other words, until the brine is delivered to the surface plant, it must be maintained substantially at the temperature at which the super-saturated solution is created within the solution cavity. Hence, prior to initiation of an operative cycle, some portions of the geological environment through which the brine solution will ascend, may require to be preheated from some external heat supply source, so as to create a "heat wall" surrounding the entire brine production apparatus in order to maintain the latter at substantially the temperature of the brine in the solution cavity.

For example, for a period of weeks or perhaps months prior to starting a production operation, depending upon the heat conducting characteristics of the ambient geology or other parameters, a supply of suitably heated fluid such as steam, hot water, oil or the like may be circulated from a heat generator located at the surface plant through the hardware of the well system, until an appropriate reservoir of heat surrounding the well is established. This will insure that the ascending brine will be maintained under the lowest possible heat loss conditions until it is delivered to the surface facilities. Also, the conduit system at the surface plant conveying the product brine to the recrystallizer or evaporator facilities will preferably be heat jacketed, to maintain the solute temperature and thereby prevent premature crystallization of the solute.

It will of course be appreciated that although only a few forms of the invention have been illustrated and described in detail hereinabove, various changes may be made therein without departing from the spirit of the invention or the scope of the following claims.

I claim:

1. The method of concomitantly mining and beneficiating a deep underground high-temperature deposit of soluble mineral including impurities disposed at such depth beneath the earth's surface as to be surrounded by a high-temperature geological environment compared to the neighborhood earth surface rock temperature, to produce a relatively pure mineral product at the relatively low earth surface ambient temperatures, said method comprising,
 - a. forming an access opening extending downwardly from the earth's surface into said deposit,
 - b. pumping a solvent liquid downwardly through said opening in direct heat-exchange relation with the ambient geology thereby heating said solvent to an elevated temperature, and then directing said heated solvent to flow in dissolution-contact relation with said high-temperature mineral to provide a highly concentrated high temperature solution of mineral, and thence to flow upwardly through said opening to a treating plant operating under substantially earth's surface temperature and pressure conditions, for separation of purified mineral from the impurities in said solution,
 - c. while simultaneously circulating and heating a heat-transfer fluid in a closed conduit system in heat exchange relation with said upflowing mineral solution to insulate it from the ambient geology and maintain

said solution at a prescribed high-temperature condition until delivery to said treating plant.

2. The method as set forth in claim 1 wherein said mineral deposit comprises a sought-for ingredient having insolubility characteristics varying in direct relation to temperature changes and impurity ingredients of inverse relation solubility characteristics, whereby the heated solvent passing through said deposit produces a dissolution product having an improved ratio of pure vs impure ingredients for discharge into said treating plant.

3. The method as set forth in claim 1 wherein said sought-for mineral ingredient is of crystalline form and whereby when said purified mineral separates from said dissolution product it precipitates in recrystallized form.

4. The method as set forth in claim 1 wherein the liquid effluent from said treating plant is fed to said solvent pumping operation thereby comprising a portion of the make-up of said solvent.

5. The method as set forth in claim 4 wherein said solvent includes a relatively lower temperature fresh water make-up ingredient.

6. The method as set forth in claim 1 wherein said treating plant comprises a series of evaporator devices, the liquid effluent from each said evaporator device comprising the feed input to the next succeeding evaporator device and the liquid effluent from the last evaporator being delivered to the solvent make-up system for recirculation through the dissolution area and treating plant in closed circuit manner.

7. The method as set forth in claim 1 wherein said solution is passed upwardly through a first tube means and wherein said heat transfer fluid flows through second tube means positionally related concentrically of said first tube means.

8. The method as set forth in claim 7 wherein said second tube means terminates short of the lower reach of said first tube means, thereby confining the heating effect on said solution of said heat-transfer fluid to only an upper portion of the solution upflow system.

9. The method as set forth in claim 7 wherein said second tube means comprises a plurality of heat transfer fluid delivery tubes extending downwardly to different levels underground thereby providing differential heat exchanging effects progressively of the length of said first tube means.

10. The method as set forth in claim 7 wherein said first tube means rests at its bottom end upon the floor of the solution cavity thereby relieving the tube suspension system of substantial portions of the weight thereof.

11. The method of concomitantly mining and beneficiating a deep underground high-temperature deposit of soluble mineral including impurities disposed at such depth beneath the earth's surface as to be surrounded by a high-temperature geological environment compared to the neighborhood earth surface rock temperature, to produce a relatively pure mineral product at the relatively low earth surface ambient temperatures, said method comprising,

flowing solvent from the surface, through the deposit and back to the surface at a rate to attain at the surface a saturated solution substantially at the ambient temperature of the deposit,

simultaneously flowing a heat exchange fluid from the surface, toward the deposit and back to the surface in a closed path in heat exchange relation to the down-going solvent and upcoming saturated solution to (a) transfer heat to the down-going solvent while (b) minimizing temperature loss of the up-coming saturated solution,

extracting heat from the saturated solution at the surface to crystallize out some of the mineral at the surface, and transferring some of said extracted heat to the heat exchange fluid.

12. The method of concomitantly mining and beneficiating a deep underground high-temperature deposit of soluble mineral including impurities disposed at such depth beneath the earth's surface as to be surrounded by a high-temperature geological environment compared to the neighborhood earth surface rock temperature, to produce a relatively pure mineral product at the relatively low earth surface ambient temperatures, said method comprising,

flowing solvent from the surface, through the deposit and back to the surface in a continuous path and at a rate to obtain a saturated solution at the surface substantially at the temperature and pressure of the deposit,

extracting heat from the saturated solution at the surface to crystallize out some of the mineral therefrom,

removing the mineral crystals from the system, and returning some of said extracted heat to the solvent flowing downwardly to the deposit.

13. The method according to claim 12 wherein the last step includes flowing a heat exchange fluid in a closed path from the surface, toward the deposit and back to the surface in heat exchange relation to said solvent.

14. The method according to claim 13 wherein said some of the extracted heat is transferred from the solvent system to the heat exchange fluid system at the surface.

15. The method according to claim 14 wherein exogenous heat is supplied to the heat exchange fluid system at the surface.

16. The method according to claim 11 wherein the up-coming saturated solution is insulated from the ambient geology and said down-going solvent by said heat exchange fluid.

17. The method of concomitantly mining and beneficiating a deep underground high-temperature deposit of soluble mineral including impurities disposed at such depth beneath the earth's surface as to be surrounded by a high-temperature geological environment compared to the neighborhood earth surface rock temperature, to produce a relatively pure mineral product at the relatively low earth surface ambient temperatures, said method comprising,

flowing solvent from the surface, through the deposit and back to the surface in a continuous path and at a rate to obtain a saturated solution at the surface substantially at the temperature and pressure of the deposit,

extracting heat from the saturated solution at the surface to crystallize out some of the mineral therefrom, removing the mineral crystals from the system, and utilizing some of said extracted heat to minimize temperature drop in the up-coming saturated solution as it flows from the deposit to the surface.

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