# United States Patent

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[31] **33351/69**


## [54] METHOD FOR RECOVERING SALT FROM A SUBSURFACE EARTH FORMATION

**11 Claims, 5 Drawing Figs.**


[52] **U.S. Cl.** ..... **299/5**
[51] **Int. Cl.** ..... **E21b 43/281**
[50] **Field of Search** ..... 299/4, 5



[56] **References Cited**

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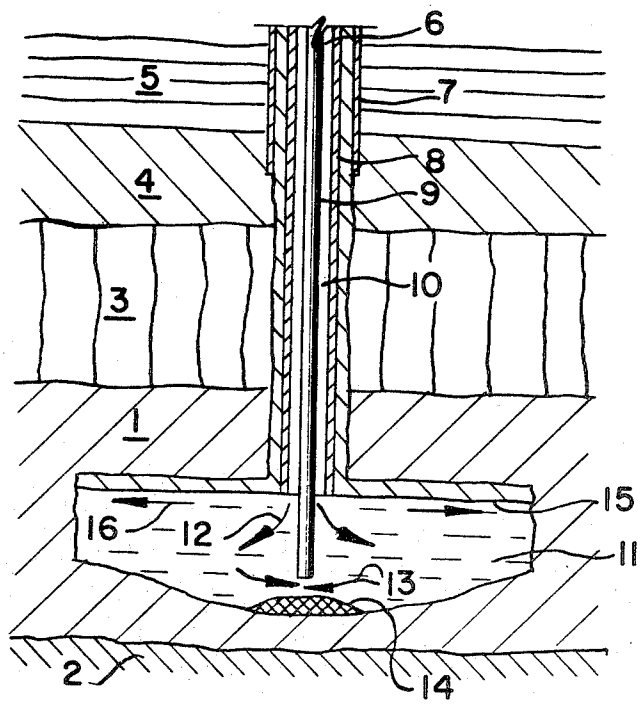
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**ABSTRACT:** A method for the recovery of salt from a subsurface earth formation containing salt therein by injecting an aqueous liquid followed by an injection of a blanket liquid into a cavity formed in the formation with salt water produced therefrom. The cavity is formed within layers present in the formation which lie below layers containing salt suitable to increase the density of solution present in the cavity and is expanded upwards into these layers. The volume of liquid injected into the cavity and the volume of liquid produced therefrom is measured per unit of time and the difference between these two volumes is determined, the injection rate of the blanket liquid being selectively increased when the difference between the two volumes exceed a predetermined value and reduced when the difference between the two volumes falls below the predetermined value.

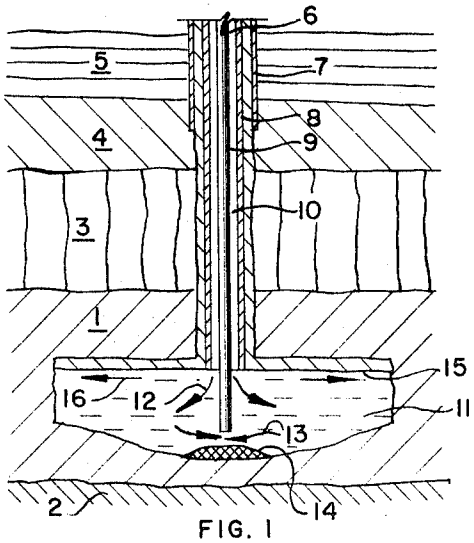



FIG. 1

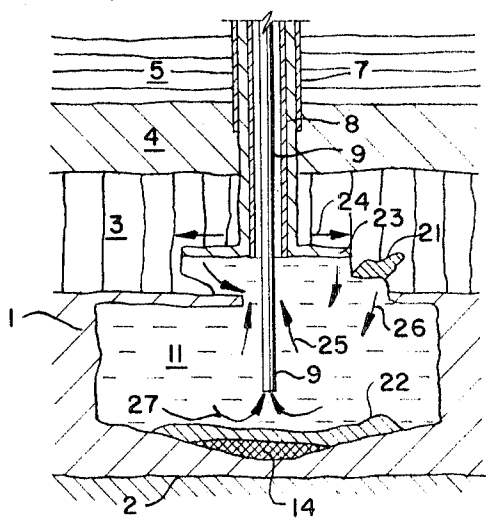



FIG. 4

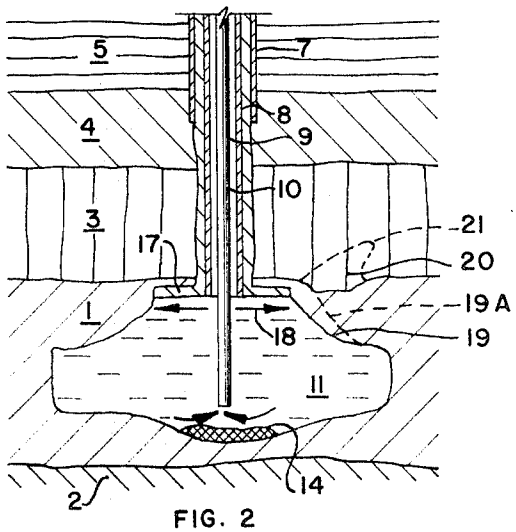



FIG. 2

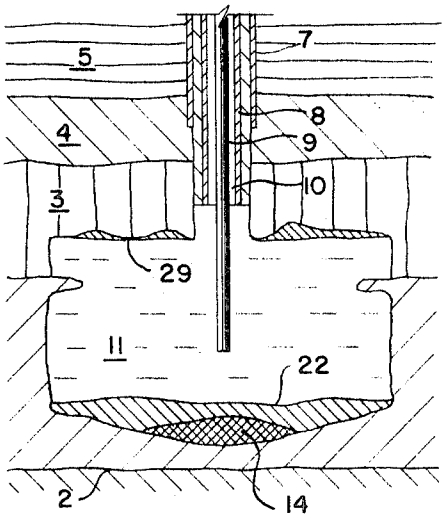



FIG. 5

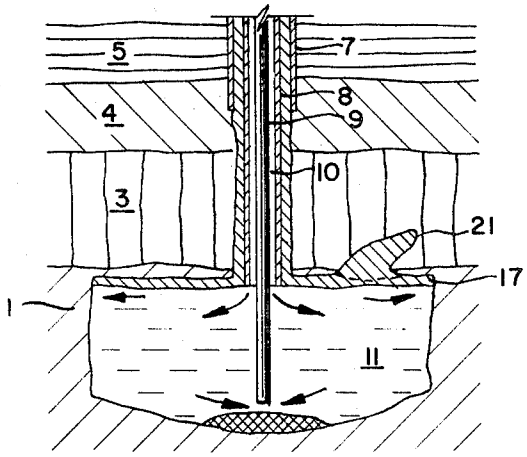



FIG. 3

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# METHOD FOR RECOVERING SALT FROM A SUBSURFACE EARTH FORMATION

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a solution mining method for recovering salts from a subsurface formation.

2. Description of the Prior Art

In such a solution mining method, aqueous liquid such as fresh water or salt water (e.g. sea water) which is unsaturated with respect to the salt to be mined is injected into a cavity established in the formation is produced from the cavity. The growth of the cavity in lateral directions is promoted by injecting a blanket liquid into the cavity, which liquid has a density smaller than that of water. Furthermore, this blanket liquid does not act as a solvent for the salt in the subsurface formation in which the solution mining method is carried out. A suitable liquid known for this purpose is oil.

In particular, the present method relates to a solution mining method suitable to be carried out in a subsurface formation comprising layers which are of different salt composition. More particularly, the present invention relates to a solution mining method, wherein the cavity is expanded from a first salt layer into a second, overlying salt layer, where by dissolving the salt from the second layer, a solution is formed that has a density which is greater than that of the solution which was present in the cavity before its expansion into this overlying layer. An example of such formation is a formation consisting of two salt layers, the greater part of the first layers consisting of halite (NaCl) and the predominant proportion of the other layers overlying the first layer consisting of bischofite ($MgCl_2 \cdot 6H_2O$).

The cavity is established in the halite layers and subsequently expanded in an upward direction into the bischofite layer. Owing to the increase of the density of the solution by the dissolution of bischofite in the halite-saturated solution present in the cavity, the newly formed relatively heavy solution will descend to the floor of the cavity, thereby displacing the old relatively light solution in an upward direction. This old solution will dissolve salt from the overlying formation layer, whereby the density of this solution is increased, and this results in a downward displacement thereof within the cavity. It will be appreciated that the rate of change from the old solution to the new solution is largely controlled by the difference in density between these two solutions, and that the growth of the cavity into the overlying layer cannot be stopped by stopping the supply of water to the cavity, but will continue until the total volume of the old solution has been converted into the new solution.

In particular when carrying out the solution mining method in a formation comprising a salt or salts which have relatively high solubilities, there is a substantial risk that once the cavity has come into contact with a layer comprising such salt or salts, the growth of the cavity will take place at such a rate that the boundaries thereof will have passed the limits set for a safe operation before any action can be taken to control the situation. This surpassing of the safe boundaries by the walls of the growing cavity means that the diameter of the cavity has increased to such an extent that there is a substantial danger of caving-in of the cavity, and this will mostly result in the loss of the cavity for normal operations.

Thus, it will be appreciated that the operational step during which the cavity on expansion thereof enters a subsurface formation layer containing a salt or salts suitable to form an aqueous solution with a density greater than that of the solution originally present in the cavity, is a very critical step in the solution mining process. Owing to the instable situation resulting from such difference in density within the fluid present in the cavity, the roof of the cavity will rapidly dissolve, and unless sufficient amounts of blanket liquid are injected to protect the roof of the rapidly expanding cavity, the dissolution of the formation layer into which the cavity is expanding will no longer be under control, and this will finally result in caving-in of the cavity.



## SUMMARY OF THE INVENTION

An object of the present invention is to prevent the loss of a cavity in a solution mining operation when expanding the cavity upward into formation layers containing salt having the property to increase the density of the solution present in the cavity.

A further object of the present invention is to control the growth of a cavity as used in a solution mining operation, in particular if layers containing salt having the property to increase the density of the solution present in the cavity come into contact with the contents of the cavity.

Still a further object of the present invention is to control the partial replacement by the density-increasing salt of a salt already dissolved in an aqueous fluid present in a subsurface cavity used in a solution mining operation, when an expansion of the cavity takes place in an upward direction, and layers containing this density-increasing salt are contacted by the fluid present in the cavity.

Another object of the present invention is the production of bischofite from a subsurface formation overlying a sodium-chloride-containing formation layer in which a cavity for solution mining of the salt is established.

The method according to the invention comprises measuring per unit of time the volume of liquid injected into the cavity and the volume of liquid produced from the cavity, determining the difference between these two volumes, increasing the injection rate of blanket liquid when this difference exceeds a predetermined value, and subsequently reducing the injection rate of the blanket liquid when this difference falls below the predetermined value.

The injection of blanket liquid may be reduced when the difference has become zero.

The increase in the injection rate of the blanket liquid may be accompanied by a reduction of the injection rate of the aqueous liquid. This injection rate of the aqueous liquid may even be reduced to zero.

Solid material, such as sand grains, may be injected into the cavity to displace the solution therefrom. The volume of this material is measured per unit of time and added to the measured volume of injected liquid when calculating the difference between the volumes that are injected into the cavity and recovered from the cavity per unit of time.

The inventive manner of controlling the growth of the cavity is based on the properties of the various salts to influence the volume of a liquid when being dissolved therein or being separated therefrom, to such an extent that the sum of the volumes of the liquid and the salt differs from the volume of the solution of the salt in the liquid, as, for example, the volume change which occurs when contacting 49 cubic centimeters of bischofite ($MgCl_2.6H_2O$) with 20 cubic centimeters of a saturated aqueous solution of soldium chloride at a temperature of 60° Centigrade. This contact results in a separation of 3 cubic centimeters of sodium chloride from the solution which has a volume of 70 cubic centimeters. The sum of the volumes after the contact and the sum of the volume prior to the contact differ by about 4 cubic centimeters, and it will be appreciated that the volume increase of 4 cubic centimeters indicates the solution of 49 cubic centimeters of bischofite in a saturated sodium chloride solution. The density of the solution after the contact is 1.341 grams/cubic centimeter against 1.184 grams/cubic centimeter prior to the contact. This results in an unstable situation in a cavity wherein a saturated sodium chloride solution comes into contact with bischofite in the roof portion of the cavity.

It will be understood that the application of the invention is not restricted to the recovery of bischofite from a subsurface formation by a solution mining operation, but may be applied with similar results to an operation for the recovery of other salts having the property of increasing the density of the solu-

tion which comes into contact with this or other salt. As an example, a bischofite deposit which comes into contact with a saturated potassium chloride solution present in a cavity which is being expanded into the bischofite layer may be mentioned.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a vertical sectional view of the first stage of the method of my invention in which a cavity has been established in top of halite layer of a subsurface salt bearing earth formation;

FIG. 2 is a vertical sectional view of the second stage of the method of my invention in which the cavity is extended into the top of the halite layer;

FIG. 3 is a vertical sectional view of the third stage in which the cavity has expanded locally into a bischofite layer within the formation, which expansion has been brought under control;

FIG. 4 is a vertical sectional view of the fourth stage in which the cavity is being expanded into the bischofite layer; and

FIG. 5 is a vertical sectional view of the final stage in which a further expansion of the cavity in an upward direction takes place.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention will now be described by way of example with reference to a solution mining operation in which a cavity is established in a halite layer and expanded into an overlying bischofite layer. The various steps taken in this method will be explained with reference to the drawing, wherein each of the various figures shows a vertical section over a well that penetrates into salt-containing formation layers.

As shown in the Figures, a halite layer 1 is bounded by a base rock 2 and a caprock 3, this latter being a bischofite layer. Overlying the layer 3 are layers 4 and 5 which may consist, as layer 2, of compositions which are of no interest to the present method. A well borehole 6 penetrates the formation layers 1, 3, 4, 5 and all the other layers (not shown) overlying the layer 5. This well borehole 6 is drilled in a manner well known in the art, and well completion equipment, also known in the art, may be used in this well borehole 6 to make the well borehole 6 suitable for the recovery of salt from the layers 1 and 3. Of the tubular equipment which is present in the well borehole 6, only casing 7, which may be cemented to the layers 4 and 5 in a known manner (not shown), injection tubing 8 and production tubing 9 are shown. The tubing 9 is concentrically arranged in the tubing 8, and the annular space 10 between these two tubings is used as a path for injecting fresh water into the formation 1, which water is handled at the surface of the earth by pumping means (not shown).

As shown in FIG. 1, a cavity 11 has been formed in the halite layer 1 by injecting fresh water through the annular space 10 (see arrows 12) and recovering water saturated with salt through the production tubing 9 (see arrows 13). Non-soluble materials are collected on the bottom of the cavity 11 in a pile 14.

The expansion of the cavity 11 is promoted in radial and horizontal directions by using a so-called blanket liquid which is injected (continuously or discontinuously) into the cavity 11 through the annular space 10 around the tubing 8. This blanket liquid has a density smaller than that of the injected water and the salts of the formation layers are not soluble therein. The use of such a blanket liquid which is often oil, is well known in the art. The blanket liquid forms a layer 15 which floats on the water present in the cavity 11, thus protecting the ceiling of the cavity from being dissolved by the water. Further, this blanket liquid fills the annular space 10 around the injection tubing 8, thus protecting the wall of the borehole 6 from being dissolved by the water. Since the fresh water injected into the cavity 11 (arrows 12) has a lower density than that of the blanket liquid, it flows over this salt water underneath the oil layers 15 (see arrows 16) towards the sidewall of the cavity 11. The ceiling of the cavity 11 is thus protected against the attack of fresh water and the cavity expands in lateral directions only. Fresh water is injected into the cavity 11 and salt water is recovered from the cavity 11 until a predetermined lateral extension of the cavity 11 has been reached. It will be appreciated that during the lateral expansion of the cavity 11, the amount of blanket liquid present in the cavity has to be increased, in order to maintain a blanket 15 of sufficient thickness.

After the cavity 11 has reached its maximum lateral boundaries the injection tubing 8 is lifted to a higher level. As is shown in FIG. 2, this level is chosen just below the boundary between the halite layer 1 and the bischofite layer 3. It will be understood that the exact position of this boundary may be measured by coring and logging operations well known in the art carried out in the borehole 6 before the solution mining method of my invention is started.

The blanket liquid is removed from the cavity through the injection tubing 8 during or after the lifting of this tubing to the new position. The new boundary between the blanket liquid and the water is now at the level of the lower end of the injection tubing 8 in the position as shown in FIG. 2. Subsequently, fresh water is injected through the injection tubing 8 and water saturated with salt is at the same time removed through the production tubing 9. The fresh water starts to dissolve salt over the region between the level of the lower end of the tubing 8 in FIG. 1 and the level of this end in the lifted position as shown in FIG. 2. The fresh water, which enters the cavity 11 through the injection tubing 8, flows in lateral directions as indicated by the arrows 18 and dissolves the salt, thereby forming a curved sidewall 19 at the upper part of the cavity 11. Sufficient amounts of blanket liquid are injected into the cavity 11 to protect the newly formed ceiling or roof of the cavity 11. The layer 17 of blanket liquid is kept at the required thickness by injecting this liquid while the upper part of the cavity 11 is expanding in lateral directions.

During the steps carried out as described above, the volume of fresh water as injected into the cavity 11 per unit of time and the volume of blanket liquid as injected into the cavity 11 per unit of time, as well as the volume of water saturated with salt as displaced from the cavity 11 per unit of time, is measured. These measurements take place at the surface of the earth (not shown) by equipment and methods well known in the art.

It will be clear that the volume occupies by water saturated with halite is slightly smaller than the sum of the volume occupies by the dry salt and the volume occupies by the water necessary to dissolve this salt and form a saturated solution. If, for example, at 60° Centigrade 74.15 $cm.^3$ of fresh water is mixed with 12.58 $cm.^3$ halite, a volume of 84.48 $cm^3$ of water saturated with halite results. Thus, if the volume of salt water displaced from the cavity is about 3 percent smaller than the volume of water injected over the same period, this is a certain indication that only halite is being dissolved by the water.

However, if as a result of the lateral expansion of the cavity, the fresh water comes into contact with a downward recess 20 of the bischofite-containing layer 3, a large increase in the volume of the displaced salt water will be measured, since bischofite has the property to increase the volume of water on being dissolved therein so that the volume of the solution is larger than the sum of the volumes of fresh water and dry bischofite before being contacted.

In the method as described by way of example, use is made of the above-mentioned property of bischofite to indicate the moment at which saturated NaCl solution in the cavity 11 comes into contact with the bischofite layer 3. If this moment of contact between the saturated NaCl solution and the bischofite which at 60° Centigrade increased the density of the solution present in the cavity 11 from 1.184 to 1.341 gram/cubic centimeter should not be known to the operator at the earth surface, the solution present in the cavity 11 would dissolve the bischofite at a very high rate owing to the difference

in densities of the old solution and of the newly formed solution, and the high solubility of bischofite in the solution. This rate would be so high that the volume of blanket liquid that is being injected to protect the roof of the cavity at the normal rate of lateral growth of the cavity **11** in the halite layer **1** is insufficient to protect those parts of the bischofite layers which come into contact with the water. Consequently, the cavity **11** would continue to grow into the bischofite layer **3** in a manner not controlled by the operator at the earth surface. This uncontrolled growth would finally result in loss of the cavity **11**.

In the method of my invention, however, the exact moment at which the first contact takes place between the solution in the cavity **11** and the bischofite layer **3** may be indicated since the total volume of the injected fresh water and the injected blanket liquid as well as the volume of the displaced salt-saturated water, are continuously measured per unit of time and compared with each other. When the sidewall **19** of the upper part of the cavity **11** has moved to the position **19A**, the water starts to dissolve the bischofite from the layer **3** and the cavity **11** grows into this layer **3** as indicated by the dotted line **21**. This is deduced from the comparison between the injected volume of liquid and the displaced volume of liquid. If the difference between these two volumes passes a predetermined value, this is an indication that the aqueous liquid has contacted the layer **3**. At the moment that the information regarding the entry of cavity **11** into the bischofite layer **3** is obtained, the supply of fresh water into the cavity **11** is stopped and the pumps normally pumping the injection water are then used for pumping blanket liquid into the cavity **11** at the highest possible rate. The blanket liquid flows into cavity pocket or portion **21** already extending in the bischofite layer **3** and displaces the water therefrom, thus sealing the bischofite from the water. The injection of the extra amount of blanket liquid into the cavity **11** is stopped when the difference between the volume of injected liquid and the volume of recovered liquid is zero. The injection of fresh water and blanket liquid is then resumed at the original rates and the upper part of the cavity **11** further expands in a lateral sense.

When the maximum lateral boundaries of the cavity **11** have been reached (as shown in FIG. **3**), the injection of fresh water is stopped and the injection tubing **8** is again lifted. As can be seen from FIG. **4**, the lower end of the injection tubing **8** is lifted to a level above the boundary between the halite layer **1** and the bischofite layer **3**. It will be appreciated that the drawing is not to scale and that the distance over which the injection tubing **8** has been lifted is somewhat exaggerated. The blanket **17** (see FIG. **3**) is removed through the injection tubing **8**. The pocket **21**, however, remains filled with blanket liquid and protects the bischofite at the boundary thereof from contact with the water in the cavity **11**. Since the water/blanket liquid interface is lifted to the level of the lower end of the injection tubing **8**, the water comes into contact with the bischofite lying below the lower end of the tubing **8** and facing the interior of the borehole wall.

As a result of the dissolution of bischofite in the solution present in the cavity **11**, halite separates from the solution and settles on the bottom of the cavity **11** in the form of a layer **22** over the pile **14** of the insoluble material. The dissolution of bischofite in halite-saturated water results in an increase in the volume of the solution present in the cavity which is greater than the volume of bischofite that has been dissolved. Consequently an amount of fluid equal to this difference in volume is displaced from the cavity **11**. This amount is further increased by the separation of halite from the solution. As has been explained above, halite is a salt that on being dissolved in water causes a volume contraction. It will be appreciated that separation of such salt from a solution causes a volume expansion.

Although fresh water may be injected during the above-described stage of the process, this is not required in view of the dissolution of the bischofite in the halite-saturated water.

Blanket liquid is injected through the annular space around the injection tubing **8** to prevent an undesired growth of the cavity **11** in an upward direction. The displacement of the halite in the solution by bischofite, and consequently the dissolution of the bischofite from the layer **3** should take place at a safe rate. Thus, for a given case, 140 $m.^3$/day bischofite may be dissolved, which means that the expansion effect amounts to about 11.5 $m.^3$/day. If further 1 $m.^3$ blanket liquid/day is injected for protecting the daily increase in the area of the cavity roof, this means that a volume of salt water not exceeding 12.5 $m.^3$ may be displaced from the cavity per day. If this volume exceeds the predetermined value of 12.5 $m.^3$ per day, all the pump capacity available for injecting liquid into the cavity **11** is used for injecting blanket liquid at a high rate. As soon as the difference between the injected volume of liquid and the recovered volume of liquid is restored to normal (i.e., at a value below 11.5 $m.^3$ per day, say 10 $m.^3$ per day), the extra injection of blanket liquid is stopped and the normal injection rate of blanket liquid is resumed. If the difference in volume as measured at the earth surface tends to increase after the injection rate of the blanket liquid has been reduced to normal value, it is desirable to increase this normal value so that a stable situation is reached during which operation the difference between the injected and recovered volumes remains substantially constant per unit of time.

It will be appreciated that during stable operation of the process, the injection rate of the blanket liquid may be gradually decreased to determine the optimal conditions for the recovery process.

If the difference between the measured volumes increases at a very high rate, it is advisable to continue the injection of blanket liquid at a high rate until the difference has been reduced to zero. At this stage of the process, there is no contact between the bischofite and the aqueous liquid. Subsequently, blanket liquid is withdrawn from the cavity **11** at a relatively low rate, while water (which may contain salt dissolved therein) is injected to keep the cavity filled with liquid. The volumes of injected and displaced liquid are measured per unit of time and as soon as the difference between these measured volumes has reached a desired value (which means that bischofite is again being dissolved by water), the injection and production is reversed, so that blanket liquid is again injected through the annulus around the injection tube **8** and water saturated with salt is again recovered through the production tubing **9**.

Thus, the above-described procedures are carried out during the lateral growth of the upper part of the cavity **11**, which expands in the bischofite layer **3** (see FIG. **4**). The movement of the blanket liquid in the layer **23** to the newly formed roof portions of the cavity **11** is indicated by the arrows **24**. The circulation of the water present within the cavity **11** is indicated by the arrows **25** and **26**. Water saturated with halite moves in the direction of the arrows **25** in an upward direction to contact bischofite in the layer **3**, thereby separating halite therefrom which is gathered on the bottom of the cavity in a layer **22**. The water saturated with bischofite descends in the cavity **11** as its density is higher than that of the water saturated with halite. This downward movement is indicated by the arrows **26**. Since, as a result of the dissolution of bischofite in the solution, the volume of the solution increases to a greater extent than the volume of the cavity, salt water will be displaced from the cavity **11** (wide arrows **27**). This salt water is recovered through the production tubing **9**.

When the expansion of the cavity **11** in the layer **3** has reached its maximum extension, the injection tubing **8**, which controls the blanket liquid/water boundary, is again lifted, and the blanket liquid present in the layer **23** is removed from the cavity. The distance over which the tubing **8** is lifted may be in the order of several meters. By the injection of water (either saturated or nonsaturated) through the production tubing **9**, blanket liquid is driven out of the cavity **11** through the injection tubing **8** till the blanket liquid/water interface has reached the lower end of the tubing **8** (vide FIG. **5**).

After the blanket liquid/water interface has been lifted to a higher level, the aqueous liquid comes into contact with fresh

parts of the bischofite layer 3 and starts to dissolve the roof the cavity.

The speed at which the roof is attacked by the water is measured by continuously determining the difference between the rate at which salt water is displaced from the cavity and the rate at which blanket liquid is injected into the cavity. If this difference rises above a predetermined value, the rate of blanket liquid injection is increased until the measured difference is sufficiently decreased. In the same manner as described above, a rapid rise in the measured difference may require the injection of a volume of blanket liquid sufficient to stop the dissolving process. If, however, the measured difference increases only slowly, such an extreme measure is not required and it may be sufficient to increase the blanket liquid injection rate only slightly in order to slow down the dissolving rate to the required degree.

It will be understood that the difference between the volumes of liquid injected and recovered per unit of time which gives an indication of the growth of the cavity, is not allowed to surpass a certain safe limit. Dissolution during a period of time above this safe limit will result in a volume increase of the cavity that can no longer be controlled by the injection of blanket liquid.

It will be obvious that such part of the method as described with reference to FIG. 5 may be repeated as many times as desired. Every time that the measured difference rises above the predetermined value, the blanket liquid injection rate is increased, whereas if the dissolution proceeds too slowly (which can be deduced from the value of the measured difference) the blanket liquid injection rate is decreased. When the measured difference becomes zero, blanket liquid is removed from the cavity through the tubing 8 by injecting water (either saturated or nonsaturated) through the tubing 9 into the cavity. If the measured difference then remains zero, the injection tubing 8 is raised again over a small distance, and blanket liquid removal from the cavity 11 continues until the value of the measured difference rises again. The blanket liquid removal is stopped when the difference has reached a predetermined value.

The above step is repeated until either the roof of the cavity 11 has reached to the top of layer 3, or the solution present in the cavity 11 has a desired concentration of bischofite. If the latter is the case, fresh water is injected into the cavity 11 through the injection tubing 8.

When the water as present in the cavity is saturated with bischofite, the growth of the cavity 11 can be controlled by the injection rate of the fresh water. Blanket liquid is injected to promote lateral expansion of the cavity.

In view of the great economic value of bischofite, the volume of water saturated with this salt and remaining in the cavity when the operations are over, should be as small as possible. To this end, solid material, which is insoluble in water, such as sand grains may be circulated into the cavity during the solution mining method. These sand grains are mixed with liquid (such as fresh or salt water and/or blanket liquid) and injected into the cavity where they are separated from the liquid and collect on the bottom of the cavity. If such solid material is injected into the cavity, the volume thereof as injected per unit of time should be taken into account when determining the difference between the liquid volume which is displaced per unit of time, and should be added to the liquid volume which is injected per unit of time.

The way in which saturated water is displaced from the water-filled cavity by circulating solid material having a density greater than that of the saturated water within the cavity, has extensively been described in a copending Pat. application Ser. No. 839,540, filed July 7, 1969.

If desired, the method of my invention may be used in a cavity which has a shape differing from that of the cavity 11 shown in the drawing. More than one well may be used. If desired, two wells may communicate with the cavity 11, wherein the injection of fresh water takes place via one of the wells and the production of water having salt dissolved therein via the other well. The blanket liquid (and the sand grains) may be injected via one well or via both wells. It will be understood that, notwithstanding the number of wells used, the total volume of liquid injection into the cavity and the total volume of liquid displaced from the cavity has to be measured per unit of time.

In the example described above, an injection tubing and a production tubing are employed, which by lifting or lowering can debouch at any desired level within the cavity or the wall. The invention is not restricted hereto. The tubings may, if desired, be provided at predetermined levels with side openings which can be opened and closed at will at any desired moment by suitable equipment which may, for example, be suspended by a cable, or they may be shortened at their lower ends by mechanical or explosive means. The tubings 8 and 9 need not be concentrically arranged, but may be suspended next to one another within the casing 7.

The water employed for dissolving the cavity in the formation layers need not necessarily be fresh water. It is also possible to use sea water or water obtained from a salt separation plant or from subsurface formations, provided that the salts from the subsurface formation layers are soluble therein. After the salts have been partly or fully removed from the water recovered from the cavity, this water may be reinjected into the cavity, but, in view of the growth of the cavity, additional water is to be supplied.

Furthermore, it will be clear that the salt-containing layers will mostly contain more than one salt. Thus, the halite layer and the bischofite layer described in the above example may contain salts other than those mentioned. Moreover, the invention is not limited to a magnesium-chloride-containing layer which is overlying a halite layer, but is also applicable to the recovery of magnesium chloride overlying salt layers consisting of salts other than halite.

As has been pointed out above, the invention is further applicable to solution mining operations wherein the cavity has at least once expanded in an upward direction into a layer of salt, which salt has the property to increase the density of the solution present in the cavity. Since the composition of the layer or layers in which the cavity has been established and into which the cavity has expanded is known, the expansion (or contraction) of the volume of liquid with regard to the volume of the cavity may be calculated as a function of the salts which are being dissolved by the liquid. Thus by measuring the difference between the volume as injected into the cavity and the volume as displaced from the cavity per unit of time, an indication is obtained of the volume of salt which is being dissolved per unit of time, and thus of the rate at which the cavity is expanding. To keep the growth of the cavity under control, this rate should not exceed a value which has to be predetermined for each case. This value has to be sufficiently low to allow blanket liquid to be supplied to the cavity at a rate sufficiently great enough to seal off the total area of the roof and to stop the dissolution of any salt from this roof. It will be appreciated that for safety reasons, it is possible to start with a certain (relatively low) value, but to increase this value afterwards if it is found experimentally that each time that the first value is surpassed, control is practically instantaneously regained by increasing the injection rate of the blanket liquid. Under these circumstances the selection of such larger value that has to be surpassed by the measured volume difference before increasing the injection rate of the blanket liquid will result in a larger time period elapsing before the magnitude of the volume difference has decreased below this larger value, but it will be clear that this may still take place within limits that are to be considered safe from an operation point of view.

Thus, the injection rate of the blanket liquid should be increased when the measured volume difference rises above a first predetermined value. The introduction of blanket liquid at the increased rate is maintained until the measured volume difference has decreased to a value below the predetermined value, for example, to zero or a value slightly different from zero. Blanket liquid is then removed from the cavity (by dis-

placing it with either fresh or salt water), and the measured volume difference will again increase. At the moment that this volume difference reaches a second predetermined value, the withdrawal of blanket liquid is stopped and the injection thereof is restarted. This second predetermined value is lower than the first predetermined value, but may, if desired, be increased if it has been found experimentally that the maximum rate at which the cavity is growing may be greater than initially determined. It will be understood that a new first value is indicated thereafter, which value is greater than the new second value.

The increase in the injection rate of the blanket liquid may be accompanied by a reduction in the injection rate of the aqueous liquid. If required, for example when the difference in volumes measured rises very rapidly, the injection rate of the aqueous liquid may even be reduced to zero. After the normal situation has again been reached, the injection of aqueous liquid may be resumed. Thus, if the injection rate of the blanket liquid is reduced, an increase of the injection rate of the aqueous liquid will take place either simultaneously or thereafter.

It will be understood that the terms "simultaneously" and "accompanied"as used herein, do not indicate that certain steps take place at exactly the same moment. Since the period over which the total solution mining operation takes place may be very long (as, for example, over several years) it will be appreciated that these terms relate to periods in which these steps take place, which periods are relatively small with respect to the total period of operation. These periods may cover several days or even weeks.

Whereinabove reference is made to the fact that the volume difference exceeds a predetermined value, this reference is intended to mean that the difference becomes greater than the predetermined value if the new salt that comes into contact with the solution in the cavity has the property of expanding the solution volume with regard to the cavity volume. However, if this new salt has the property to contract the volume of the solution (or the total volume of the solution and the old salt which may be separated from the solution as a result of the dissolution of the new salt) with respect to the volume of the cavity, the above reference is intended to mean that the difference in volume becomes smaller than the said predetermined value. It will be understood that, in this latter case, the injection rate of blanket liquid, after having been increased, is again reduced when the difference in volume has grown above the predetermined value.

Furthermore, the use of the present method is not restricted to the particular type of blanket liquid, such as oil, mentioned in the example. Any other type of blanket liquid may be employed, provided that the liquid does not dissolve the salt or salts present in the formation or formations in which the cavity is formed. The blanket liquid may not be miscible with the solvent used in the solution mining process and may further not be a solvent for the solid material used for displacing the saturated solution from the cavity, if such solid material is used. Further, this liquid has to have a density smaller than the density of the solution present in the cavity.

The required information on the size of the cavity may be obtained by the use of logging equipment and methods which are well known in the art. One of such methods applies acoustic waves which are generated by equipment lowered into the cavity. The reflection of these waves against the wall of the cavity is received by this equipment and the time difference between emission and reception of these waves is an indication of the distance between the wall and the place where the equipment is located.

Moreover, it will be appreciated that, especially if the contraction (or expansion) of the volume of the solution present in the cavity (this volume including the volume of salt separated from the solution) is relatively small relative to the volume of the cavity, some other factors are to be taken into account. Such factors are, for example, the volume changes as a result of pressure variations and/or temperature variations within the cavity and subsidence of the cavity. In this case, suitable correction factors have to be calculated and to be applied when comparing the measured difference between the volumes of the injected and recovered liquid with the predetermined value.

I claim as my invention:

1. A method for the recovery of salt from a subsurface earth formation containing salt therein wherein a cavity is formed in the formation and an aqueous liquid and a blanket liquid are injected into the cavity formed in the formation and salt water is produced therefrom, the cavity being formed within layers present in the formation which lie below layers containing salt suitable to increase the density of solution present in the cavity, the blanket liquid being injected after the aqueous liquid and forming a blanket thereon, said cavity being expanded upwards into the latter-mentioned layers, characterized in that the volume of liquid injected into the cavity and the volume of liquid produced from the cavity is measured per unit of time, the difference between these two volumes is determined, the injection rate of the blanket liquid is selectively increased when the difference between the two volumes exceeds a predetermined value, and reduced when this difference falls below the predetermined value.

2. The method of claim 1 including the step of reducing the injection rate of the blanket liquid when the difference has become zero.

3. The method of claim 1 including the step of accompanying the increase in the injection rate of the blanket liquid by a reduction of the injection rate of the aqueous liquid.

4. The method of claim 3 including the step of reducing the injection rate of the aqueous liquid to zero.

5. The method of claim 4 including the step of subsequently increasing the injection rate of the aqueous liquid.

6. The method of claim 4, wherein the step of increasing the injection rate of the aqueous liquid includes the step of increasing the injection rate simultaneously with the reduction of the injection rate of the blanket liquid.

7. The method of claim 5 including the step of resuming the injection of water after the solution present in the cavity has reached a concentration of the salt suitable to increase the density of the solution present in the cavity.

8. The method of claim 1 including the step of stopping the injection of blanket liquid and removing said blanket liquid from the cavity before reducing the injection rate of the blanket liquid.

9 The method of claim 8 including the step of simultaneously replacing the removed blanket liquid by an equal volume of water.

10. The method of claim 7 wherein the step of resuming the injection of water includes the step of injecting water saturated with salt.

11. The method of claim 1 including the step of injecting solid material into the cavity, measuring the volume of the solid material and adding said measured volume of solid material to the measured volume of injected liquid when calculating the difference between the volumes which are injected into the cavity and produced from the cavity per unit of time.