United States Patent

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New York, N.Y.
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[33] Netherlands
[31] 6902652

[54] **METHOD FOR RECOVERING SALT FROM A SUBSURFACE EARTH FORMATION BY SOLUTION MINING**
13 Claims, 7 Drawing Figs.

[52] U.S. Cl. 299/5, 61/35
[51] Int. Cl. E21b 43/28
[50] Field of Search 299/3–5; 61/.5, 35

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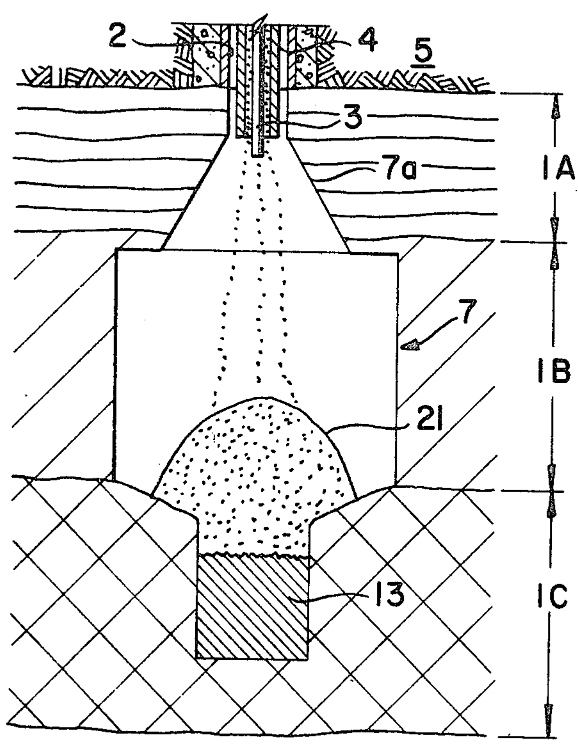
ABSTRACT: A method for the recovery of salt from a subsurface earth formation containing salt therein by circulating an aqueous liquid through the formation to form a cavity therein. The salt dissolved in the aqueous liquid is removed from the cavity and a solid substance, such as sand, is circulated into the cavity in an amount sufficient to form a pile of a height filling a substantial portion of the cavity and displace the salt-containing liquid remaining in the cavity prior to closing in the cavity.



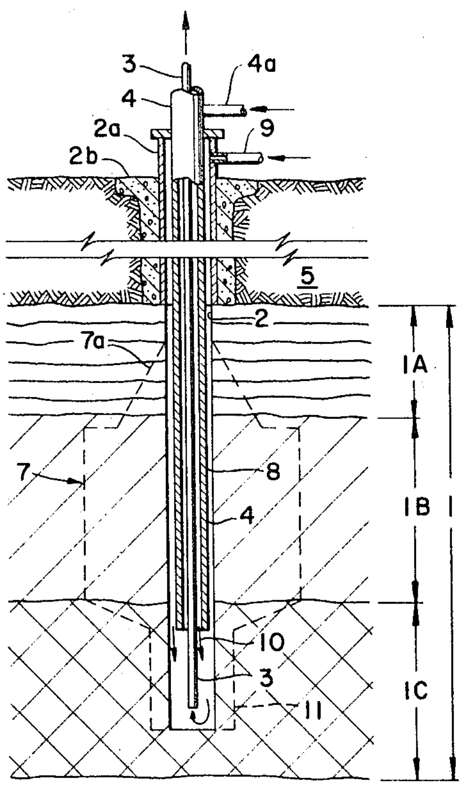


FIG. 1

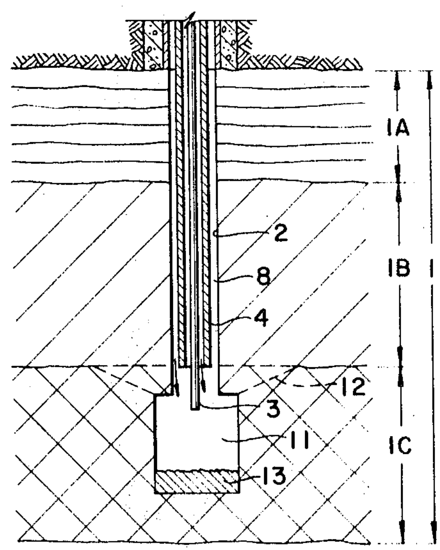


FIG. 2

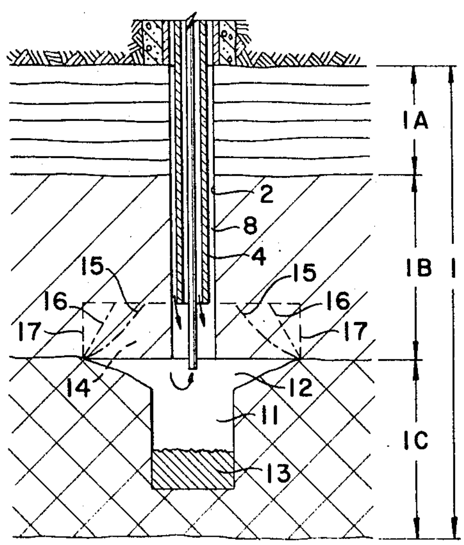


FIG. 3

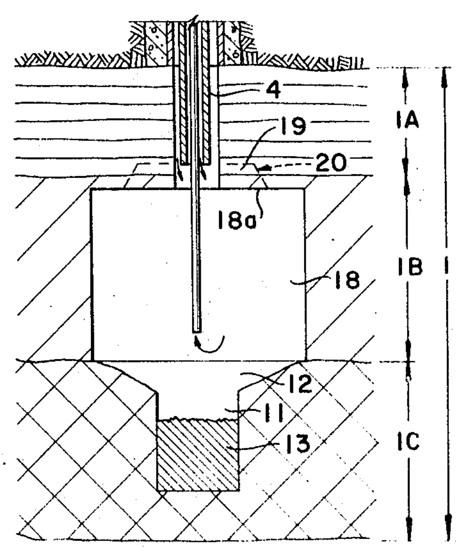


FIG. 4

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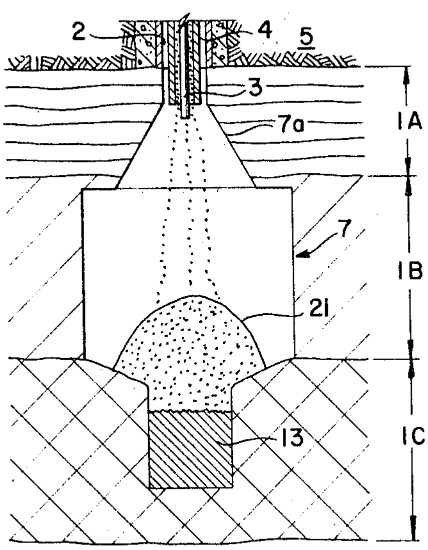

FIG. 5

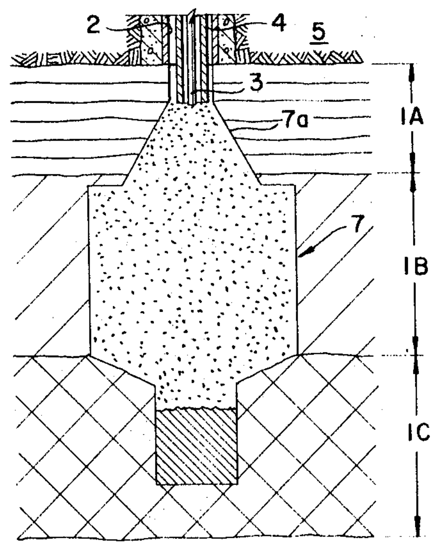

FIG. 6

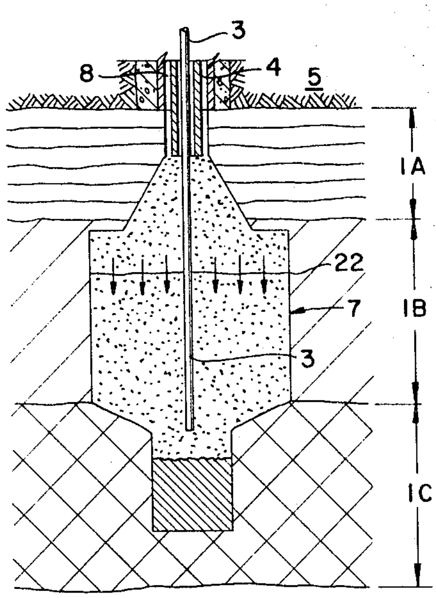

FIG. 7

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METHOD FOR RECOVERING SALT FROM A SUBSURFACE EARTH FORMATION BY SOLUTION MINING

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to a method for the recovery of salt from a subsurface earth formation.

2. Description of the Prior Art

In recovering salt from subsurface earth formations containing salt therein, an aqueous liquid such as fresh water or sea water or other water that is not saturated with salt is circulated through the salt-bearing formation by way of two conduits each communicating at one end thereof with the surface of the earth. The water is injected into the formation through one of the conduits, while water in which salt from the formation is dissolved is returned to the surface of the earth through the other conduit. As a result thereof a cavity is formed within the formation which cavity is filled with water in which salt from the formation is dissolved. To prevent the cavity from collapsing, it can only be washed out in the formation to a certain diameter (dependent inter alia on the depth of the formation). In order to recover a maximum quantity of salt from a certain formation, more than one cavity in the formation is washed out. The cavities which have reached the permissible diameter are closed in, which implies that the injection of the aqueous liquid not saturated with salt into the cavity is discontinued and that the conduits leading to the cavity are shut off.

A disadvantage of this method is that a large amount of salt which is no longer recoverable remains behind in the formation, i.e. the salt dissolved in the water present in the cavity in the formation.

This salt could be driven from the cavity to the surface of the earth by continuing the water injection but this would result in the fresh quantity of water dissolving a fresh quantity of salt, involving an increase in the diameter of the cavity.

SUMMARY OF THE INVENTION

The object of the invention is the recovery of the salt present in the cavity formed within a salt-bearing subsurface earth formation in the dissolved state prior to closing in the cavity, without any danger of the ceiling (or roof) of the cavity collapsing.

According to the invention, before closing in the cavity, salt water is driven from the cavity to the surface of the earth by circulating into the cavity a solid substance which is not soluble in the aqueous liquid, in a quantity sufficient to form within the cavity a pile having a height which is substantially equal to the height of the cavity.

The term "closing in," as used throughout this specification includes the discontinuance of the injection into the cavity of the aqueous liquid which is not saturated with the salt (or the salts) from the formation, and the shutting off of the conduits leading to the cavity.

The term "circulating into the cavity," as used throughout this specification, includes the transportation of a liquid-borne solid substance from a point at the surface of the earth through a conduit to a cavity located in a formation, the solid substance and the liquid being substantially separated in the cavity and the liquid flowing back to the surface of the earth through a second conduit.

The circulation of a solid substance such as sand into cavities which are washed out in salt formations is known inter alia from U.S. Pat. No. 3,339,978, which discloses a method for the dissolution of salt from a formation, in which the dissolution of the bottom of the cavity thus formed is inhibited by a layer of sand applied to this bottom.

The circulation of the solid substance into the cavity may, in the method according to the invention, be carried out during the washing out of the cavity by entraining the solid substance with the aqueous liquid which is not saturated with the salt (or the salts) from the formation and which is injected into the cavity. This may be effected continuously or discontinuously.

If it is desired to circulate the solid substance into the cavity without simultaneously dissolving salt in the cavity, the solid substance may be circulated into the cavity by means of water which has already been saturated with the salt (or the salts) from the formation. In this case a portion of the aqueous liquid saturated with salt is mixed again with the solid substance after its return to the surface of the earth and the mixture thus obtained is passed to the cavity, where a major part of the solid substance separates from the aqueous liquid by gravity. This circulation of sand into the cavity by means of aqueous liquid saturated with salt can be effected at fairly regular intervals during the salt recovery process. If desired, however, the required amount of solid substance can also be circulated into the cavity at the end of the recovery process.

The effect of circulating sand into the cavity in a quantity sufficient to form a pile in the cavity of a height which is substantially equal to the height of the cavity is that the volume in the cavity available for liquid decreases and that a larger volume of salt-laden liquid is driven from the cavity to the surface of the earth than is injected. The salt contained in the differential volume of liquid is separated at the surface from the liquid. The operations for effecting this separation are known in the art and further explanation is not deemed necessary.

If the layer containing the salt to be recovered has another overlying salt layer which is of little or no economic significance, the cavity in the salt layer to be recovered may advantageously be provided with a conical ceiling which substantially extends into the layer containing salt of minor economic significance. Maximum efficiency in filling up the cavity with solid substance is achieved if half the apex angle of the conical ceiling is equal to the complement of the angle of repose of the pile of the solid substance dumped in bulk under water.

In the situation described above, the salt to be recovered is also present in the dissolved state in the water in that part of the cavity which extends into the economically insignificant upper layer. Displacement from the cavity of a maximum portion of the water saturated with salt now makes it possible to recover a greater part of the salt than would be the case if the cavity had extended only into the layer consisting of salt of high economic value.

When the cavity is first brought at the desired diameter, only a dilute salt solution is obtained, from which the salt might only be recovered at great cost. If the salt to be recovered has underneath it another salt layer of little or no economic significance, the widening of the cavity to the desired diameter is carried out in this economically insignificant underlying layer. Such an underlying layer is often present.

BRIEF DESCRIPTION OF THE DRAWING

FIGS. 1 through 4 are vertical cross-sectional views through a salt-bearing subsurface earth formation showing four stages of the establishment of the cavity in the salt-bearing formation; and

FIGS. 5 through 7 are vertical cross-sectional views showing three stages of the displacement of salt water from the cavity before the latter is closed in.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1 of the drawing, a well borehole 2 is shown extending into a salt-bearing formation 1. Since, in the preferred method according to the invention, the well borehole 2 serves as both a production well and as injection well, the well borehole contains at least a pair of conduits such as a production tube 3 and an injection tube 4. The tubes 3 and 4 are preferably arranged concentrically and the annular space between the tubes 3 and 4 serves as path for the injected aqueous liquid. At the point where the well borehole 2 passes earth formation 5 overlying the formation 1, it is provided with a casing 2*a* which is preferably connected with the formation 5 by means of a cement layer 2*b*. If desired, the casing 2*a* and the cement layer 2*b* may be extended into the upper part of the layer 1A of the formation 1. An annular outlet 4a is disposed at the upper portion of injection tube 4 for introducing liquid into the annular space between tubes 3 and 4.

The salt-bearing formation 1 may consist of three layers 1A, 1B and 1C. The layers 1A and 1C may contain salt of minor economic value only. The layer 1B which is in between the layers 1A and 1C may consist of salt of high economic value.

The shape of the cavity 7 to be washed out in the formation 1 is indicated by means of the dotted lines in FIG. 1.

Before washing out the formation 1, the well borehole 2 is filled with a liquid in which the salts from the layers 1A, 1B and 1C of the formation 1 do not dissolve or hardly at all. Preferably oil is selected for this liquid. Subsequently, an aqueous liquid is injected into outlet 4a and thus into the annular space between conduits 3 and 4, which liquid flows in the direction of arrows 10 and leaves the borehole 2 through the production tube 3. During the passage of this liquid, which may be water not saturated with salt, such as fresh water, water from an associated salt refinery or sea water, salt from the formation 1 is dissolved, as a result of which a space 11 is formed. During the formation of the space 11, the ceiling or roof of this space is protected from being washed out by a layer of an immiscible fluid, such as oil, which may be supplied through an annular space 8 formed between the wall of well borehole 2 and the injection tube 4, as by injection down annular outlet 9.

After the formation of the space 11 (see FIG. 2), which for the remaining part of the recovery process serves as a reservoir for undesired rock which is insoluble in water, the injection tube 4 is lifted over a small height, as for example, to approximately the upper boundary of the salt layer 1C. The oil which protects the roof of the space 11 from dissolving is partly withdrawn through the injection tube 4. The new oil/water interface thus reaches a position on a level with the lower end of the tube 4. The water which is subsequently supplied to the borehole 2 through the injection tube 4 enlarges the borehole 2 laterally in situ, the roof of a space 12 thus formed being protected by the supply of oil. Withdrawal of water with the salt dissolved therein is effected through the tube 3, which in the meantime has been lifted to such a height that its lower end stays clear of rock debris 13 which collects on the bottom of the space 11. Enlargement of the space 11 does not occur since it is always full of water which is saturated with salt.

Once the space 12 has reached the desired diameter, the injection tube 4 is lifted again over a predetermined height (see FIG. 3). The oil forming the layer which protected the ceiling of the space 12 from being dissolved by the water not saturated with salt and flowing in through the injection tube 4, is subsequently discharged to the surface of the earth through the tube 4 until a new oil/water interface is formed on a level with the lower end of the tube 4.

Water which is not saturated with salt is subsequently supplied to the borehole 2 through the injection tube 4. The water first dissolves salt from the wall of the borehole 2 and subsequently flows, saturated with salt, through the spaces 12 and 11 to the production tube 3 and through this tube to the surface of the earth. Enlargement of the spaces 11 and 12 does not occur since the liquid in these spaces is saturated with salt. Oil for the protection of the ceiling formed during this washing out of a space 14 is supplied through the annular space 8. The manner in which the sidewall of the space 14 is formed is indicated by the lines 15, 16 and 17 which represent successive stages.

When the sidewall of the space 14 has reached the position indicated by the lines 17, the space 14 is substantially cylindrical in shape. Subsequently, the injection tube 4 is lifted again over a predetermined height. At this stage the same measures as described for the formation of the space 14 are taken to form a second space (not shown) of substantially cylindrical shape, which second space adjoins the upper part of the already existing space 14. This procedure is repeated several times until a space 18 has been formed (see FIG. 4), the roof 18a of which is located near the upper boundary of the salt layer 1B.

The last part of the cavity 7 to be formed is a space having a conical roof, which roof is formed mainly in the layer 1A consisting of salt of minor economic significance. In order to form the conical roof 7a of the cavity 7, the production tube 4 is pulled up to the height indicated in FIG. 4 and a space 19 is washed out with the use of oil to protect the roof of the space 19 thus formed. The circulation of water not saturated with salt through the space 19 is interrupted when the sidewall 20 of this space is substantially conical in shape and is formed at the place shown.

A new space having a conical sidewall is subsequently formed on top of the space 19 in the manner described previously, which procedure is repeated as many times as is necessary for the cavity 7 to have a substantially conical roof 7a such as schematically shown in FIG. 5. At this stage the space 7 has the maximum permissible dimensions. A further increase in the volume of this cavity in a radial direction would result in a collapse and the recovery of salt from the wall of this cavity is therefore to be terminated. The cavity 7 is to be closed in.

Prior to abandonment of the cavity 7, a maximum quantity of the salt present in the cavity in the dissolved state is first brought to the surface of the earth. This is effected by circulating sand into the cavity, which circulation takes place by preferably mixing at the surface an insoluble substance, such as sand, with a fluid, such as water, saturated with salt, and by injecting this mixture into the cavity 7 via the injection tube 4. well

When this mixture flows out of the tube 4 into the cavity 7 (see FIG. 5) the greater part of the sand is separated under the influence of gravity from the water saturated with salt. The sand sinks to the bottom of the cavity (see pile 21) while the water saturated with salt flows back through the production tube 3. As is clear from FIG. 5, the production tube 3 has been pulled up to such a height that the lower end thereof cannot be immersed in the growing sandpile 21. Alternately, the sand may be injected down tube 3 with the saturated water flowed back up tube 4.

The salt-saturated water flowing back from the cavity 7 is mixed again with sand at the surface and subsequently returned to the cavity 7 through the injection tube 4. However, since the sand circulated into the cavity takes up part of the volume of the cavity 7, an equal volume of water saturated with salt is displaced from the cavity 7. In other words, the volume of the sand grains which are circulated into the cavity from the top of the well borehole 2 is equal to the volume of salt-saturated water which can be withdrawn from the circulated water.

The quantity of injected sand is so selected that the height of the pile formed by the sand is substantially equal to the height of the cavity 7. If the half apex angle of the conical roof 7a of the cavity 7 is selected equal to the complement of the angle of repose of sand dumped in bulk under water, the sand circulated into the cavity 7 will ultimately fill this cavity substantially completely as shown in FIG. 6.

At this stage, only the pore space of the sand body present in the cavity 7 is still filled with an aqueous liquid, which is saturated with salt. If the amount of salt involved is deemed too valuable to be left behind in the cavity 7, this remaining quantity can further be recovered in the following manner. To this end the production tube 3 is lowered until the lower end thereof is located near the bottom of the cavity 7 as shown in FIG. 7. There are several methods of lowering the tube 3 through the sand body. Since these methods are well known in the art, as for example drilling by means of sand bailing, further explanation is not deemed necessary.

Subsequently, a liquid in which neither the solid substance nor the salt is soluble (for example a hydrocarbon such as crude oil) is injected into the cavity 7 through the injection tube 4 and/or the annular space 8. In the pore space of the sand body, the oil keeps floating on the water saturated with salt and, owing to the increasing quantity of oil supplied under pressure, the oil/water level **22** in the cavity **7** falls, at the same time forcing the salt-saturated water through the pore space in the direction of the lower end of the production tube **3**, through which tube **3** the salt-saturated water is passed to the surface of the earth.

The conduits leading through the well borehole **2** to the cavity **7** are shut off when all the water has been driven from the pore space of the sand body present in the cavity **7**. The cavity **7** is then abandoned.

It will be clear that this shutting off can also take place at an earlier time, if displacement of salt-saturated water from the pore space of the sand in the cavity is not carried out.

Obviously, the invention is not limited to the recovery of salt from cavities which are provided with a conical roof or ceiling.

It is not necessary to wait to circulate the sand into the cavity **7** until after the complete formation of the cavity **7**. The sand may also be circulated into the cavity at earlier stages of the formation of the cavity **7**. If desired, the sand may also be injected during the period in which salt is being dissolved. This injection can be continuous or discontinuous. Sand is then mixed with water which is not saturated with salt whereupon the mixture is injected through an injection tube into the formation to be washed out. The water dissolves salt and thus forms a cavity, while the sand remains behind in this cavity. The salt-saturated water is discharged from the cavity through a production tube to the surface of the earth. If desired, it is possible to add during certain periods salt to the water in the injected sand/water mixture in order to permit the injection of sand into the cavity without the volume of the cavity increasing simultaneously. If the addition of salt is insufficient for saturating the water, a reduced increase of the volume of the cavity per unit of time can be achieved in relation to the use of a fully unsaturated liquid.

It should be noted that use can be made of the methods and equipment well known in the art for determining the dimensions of the spaces **11**, **12**, **14**, **18** and **19** of the cavity **7**. For example, in one such method, acoustic waves are employed which are generated by means of equipment lowered into the cavity which equipment also receives the waves reflected back against the wall of the cavity. The interval between transmission and reception of these waves gives an indication of the distance between the wall and the location of the equipment.

Furthermore, the invention is not limited to the method of washing out the cavity **7**, which method has been described above by way of example, nor to the shape of this cavity. It is also possible to use more than one well borehole. Thus, use can be made of two well boreholes, the injection of aqueous liquid taking place through one of the well boreholes and the production of salt-saturated liquid through the other.

In the example described herein above, use is made of an injection tube and a production tube, each of which can communicate with the cavity at any level desired by being lifted or lowered. However, the invention is not limited thereto. If desired, the injection tube can be provided with closable lateral openings at predetermined points, which openings can be opened and closed at any moment desired, for example by means of operating equipment suspended from a cable. Furthermore, the tubes **3** and **4** need not be concentric; if desired, they can be suspended in the borehole next to each other.

It will also be clear that instead of the sand used in the example described above, use can be made of any other solid substance, provided the grains or particles thereof are sufficiently small to pass through the casing, and which has a specific gravity sufficiently different from that of the transport liquid that it can be separated in the cavity by gravity from the transport liquid. The cost of the solid substance should of course be sufficiently low relative to the cost of the salt to make the recovery economical.

The water required for washing out the cavity need not exclusively consist of fresh water. Use can also be made of sea water or water obtained from underground formations, provided the salt or the salts from the salt-bearing layer are soluble in that water. After complete or partial separation of the salt or the salts from the water passed through the cavity, the water can be reinjected into the cavity. Continuous addition of extra water is necessary, however, as a result of the increasing volume of the cavity.

It will be clear that salt layers in underground formations generally contain more than one type of salt. Whenever reference is made to salt or salts in the subject application, it is to be understood that salt or a mixture of salts which at any rate contains salt or salts which can be recovered from the formation by means of washing out by the method according to the invention.

The salt layers in which the method of the invention may be carried out may lie horizontally (as described herein above) or may be sloping layers.

In the example shown in FIG. **1**, the conical roof **7*a*** does not adjoin the upper edge of the space **18**, FIG. **4**, although this is feasible. It has been found, however, that an optimum salt production is obtained by leaving a shoulder of approximately one-fifth of the radius of the cylindrical space **18**. The exact optimum width of this shoulder depends to some extent on the pore content of the deposited sand.

In the embodiment according to the invention described herein above, the cavity **7** is arranged in three superimposed layers **1A**, **1B** and **1C**, the layers **1A** and **1C** of which may contain salt of minor economic value. For this reason the space **18**, which constitutes the major part of the cavity **7**, has been established in the layer **1B** which may contain salt of high economic value. If desired, the cavity **7** may consist only of the space **18** and the associated conical upper space, the space **18** being established substantially completely in a salt layer of high economic significance and the conical upper space **7*a*** being accommodated substantially completely in a salt layer of minor economic significance.

If the layer **1B** is confined both upwardly and downwardly by layers which are not soluble in water, the cavity **7** preferably comprises only the space **18**. Moreover, if the salt layer only comprises the layers **1B** and **1C**, the cavity **7** may be formed either by the space **18** alone or by the spaces **11**, **12** and **18**.

I claim as my invention:

1. A method for recovering salt from a subsurface salt-containing earth formation, the method comprising the steps of:

providing at least two conduits which form flow paths for fluid communication into and out of the subsurface earth formation,

circulating an aqueous liquid solvent through said conduits and into contact with said earth formation to form a substantially liquid-filled cavity in said formation by dissolution of said salt,

continuing circulation of aqueous solvent to enlarge said cavity to a selected radius less than the radius at which said cavity would collapse,

circulating a solid substance insoluble in said aqueous solvent and having an angle of repose into said cavity to displace salt-containing liquid from the cavity, the amount of solid circulated being sufficient to substantially fill said enlarged cavity with a porous pile of solid substance,

collecting said displaced salt-containing liquid, and

recovering salt from said displaced salt-containing liquid.

2. The method of claim **1** wherein the step of circulating a solid substance includes the step of circulating an aqueous liquid containing a solid substance substantially consisting of sand.

3. The method of claim **2** wherein the step of circulating an aqueous liquid containing a solid substance includes the step of circulating water containing said solid substance.

4. The method of claim **2** including the step of injecting an aqueous liquid containing said solid substance in which aqueous liquid the salt from the formation is insoluble, immediately prior to closing in said cavity.

5. The method of claim 1 wherein the step of circulating said aqueous liquid solvent is periodically interrupted and that a aqueous liquid containing said solid substance is injected during at least part of this interruption, in which aqueous liquid the salt from the formation is insoluble.

6. The method of claim 1 including the step of driving liquid from said cavity; and

returning a portion of said driven liquid to the cavity after first mixing said driven liquid with said solid substance.

7. The method of claim 1 wherein the step of circulating said solid substance into the cavity includes the step of circulating an aqueous liquid saturated with the salt originating from the formation.

8. The method of claim 1 including the step of forming a substantially conical ceiling at the upper portion of said cavity prior to closing in said cavity.

9. The method of claim 8 wherein the step of forming a substantially conical ceiling includes the step of forming a conical ceiling having a half apex angle equal to the complement of the angle of repose of the pile of solid substance formed in said cavity.

10. The method of claim 1 including the steps of

injecting into the cavity a liquid in which neither the solid substance nor the salt is soluble in an amount sufficient to substantially fill the pore space of the porous pile of solid substance formed in the cavity and thereby displace salt-containing liquid from said pore space; and

collecting said displaced salt-containing liquid and recovering salt therefrom.

11. The method of claim 10 wherein the step of injecting said latter-mentioned liquid includes the step of injecting a liquid substantially consisting of hydrocarbons.

12. The method of claim 11 wherein the step of injecting a liquid substantially consisting of hydrocarbons includes the step of injecting a liquid substantially consisting of crude oil.

13. The method of claim 1 wherein the step of circulating said solid substance to form a pile in said cavity includes the step of forming a pile of a height which is substantially equal to the height of said cavity.