Oct. 15, 1968 C. L. HUNDLEY, JR., ET AL 3,405,974

PROCESS OF UNDERGROUND SALT RECOVERY

Filed Feb. 21, 1966 4 Sheets-Sheet 1

FIG. 1

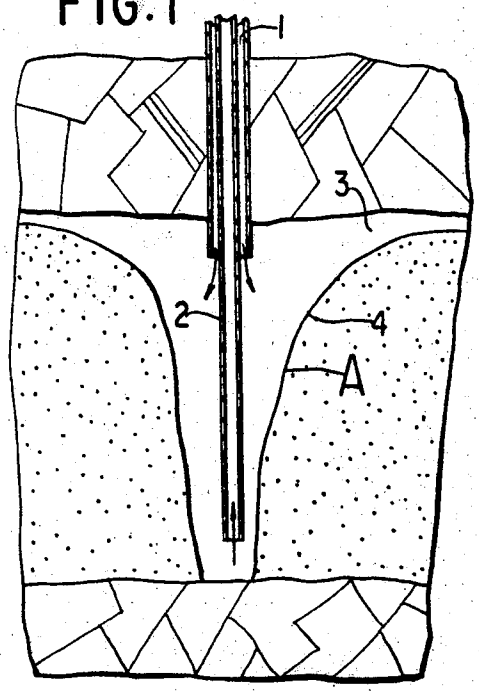
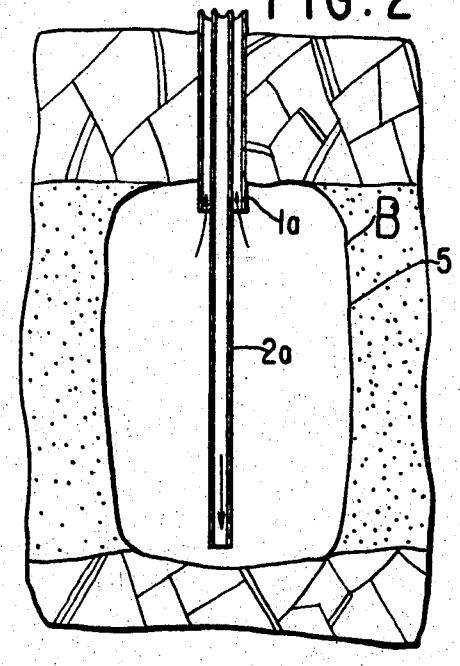


FIG. 2



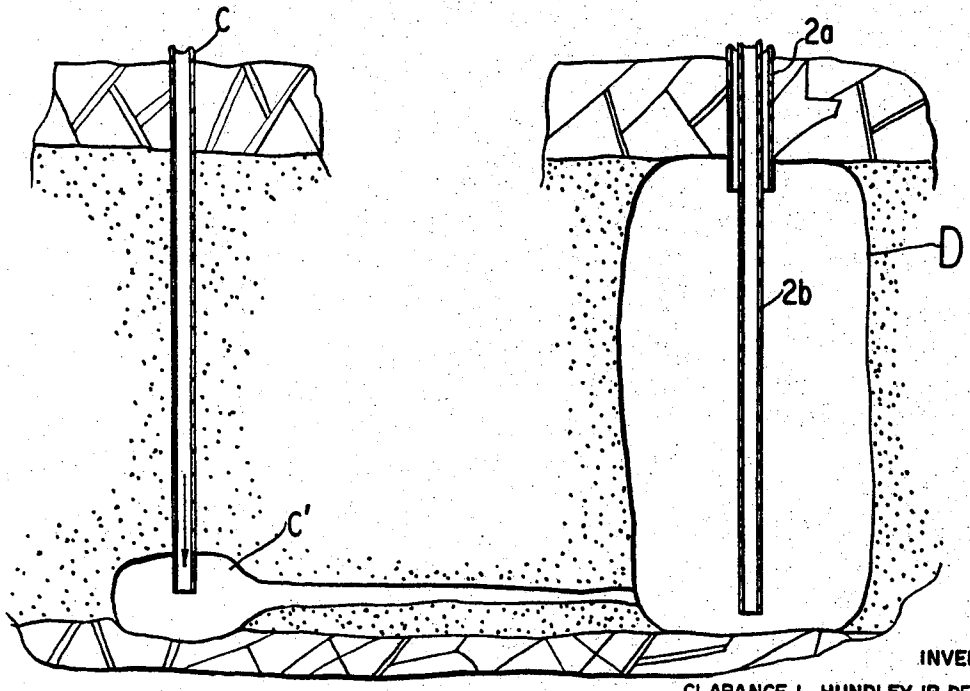


FIG. 3

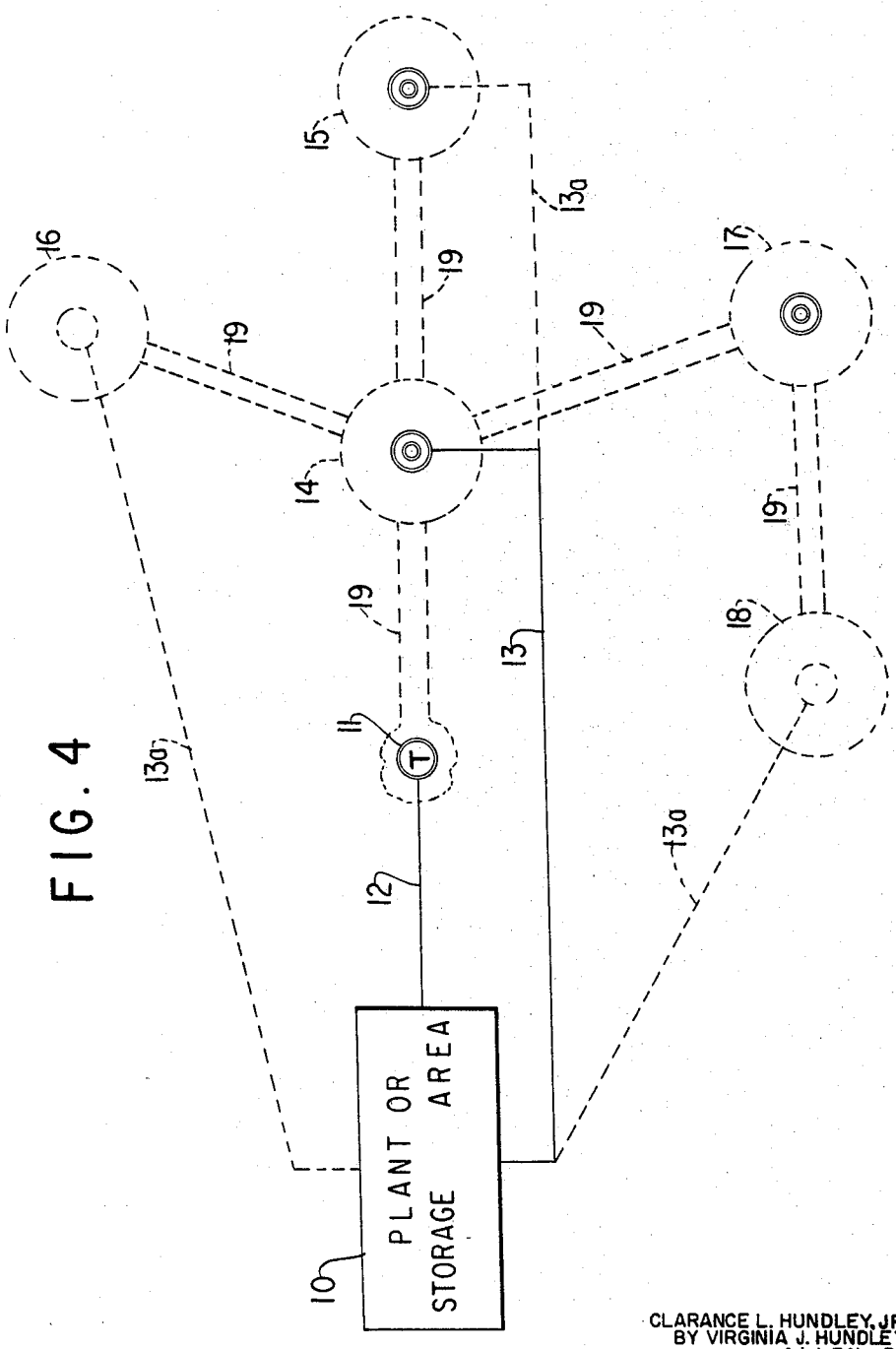
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PROCESS OF UNDERGROUND SALT RECOVERY

Filed Feb. 21, 1966 4 Sheets-Sheet 2

FIG. 4



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PROCESS OF UNDERGROUND SALT RECOVERY

Filed Feb. 21, 1966 4 Sheets-Sheet 3

SINGLE WELL SYSTEM
OR
MULTIPLE WELL SYSTEM
NOT FRACTURE(CONNECTED)

FIG. 5a

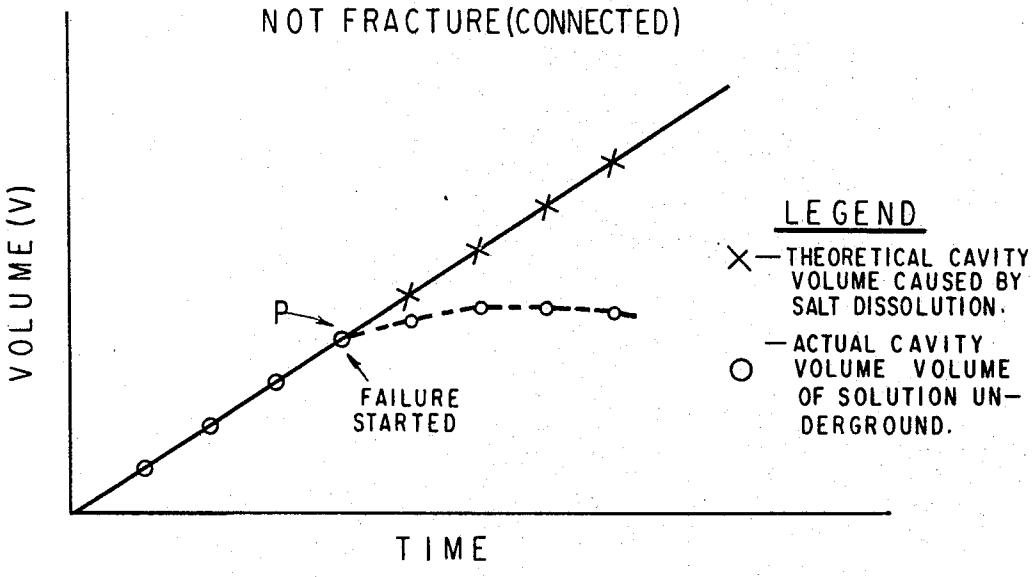
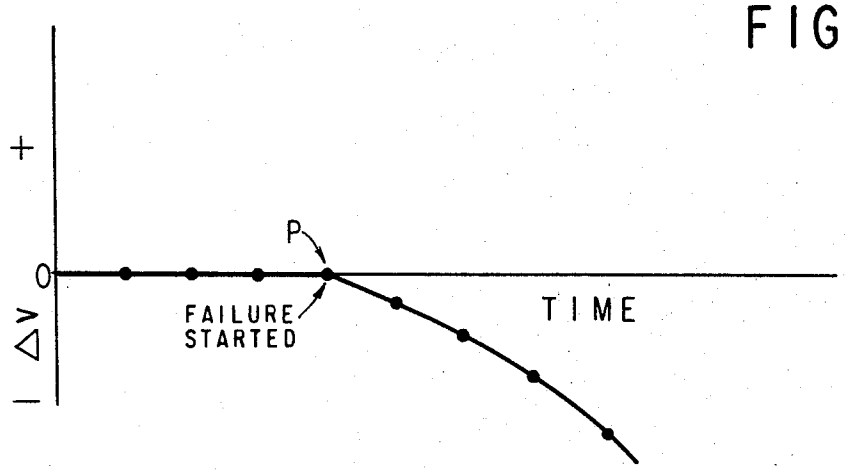


FIG. 5b



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FRACTURE CONNECTED WELL SYSTEM

FIG.6a

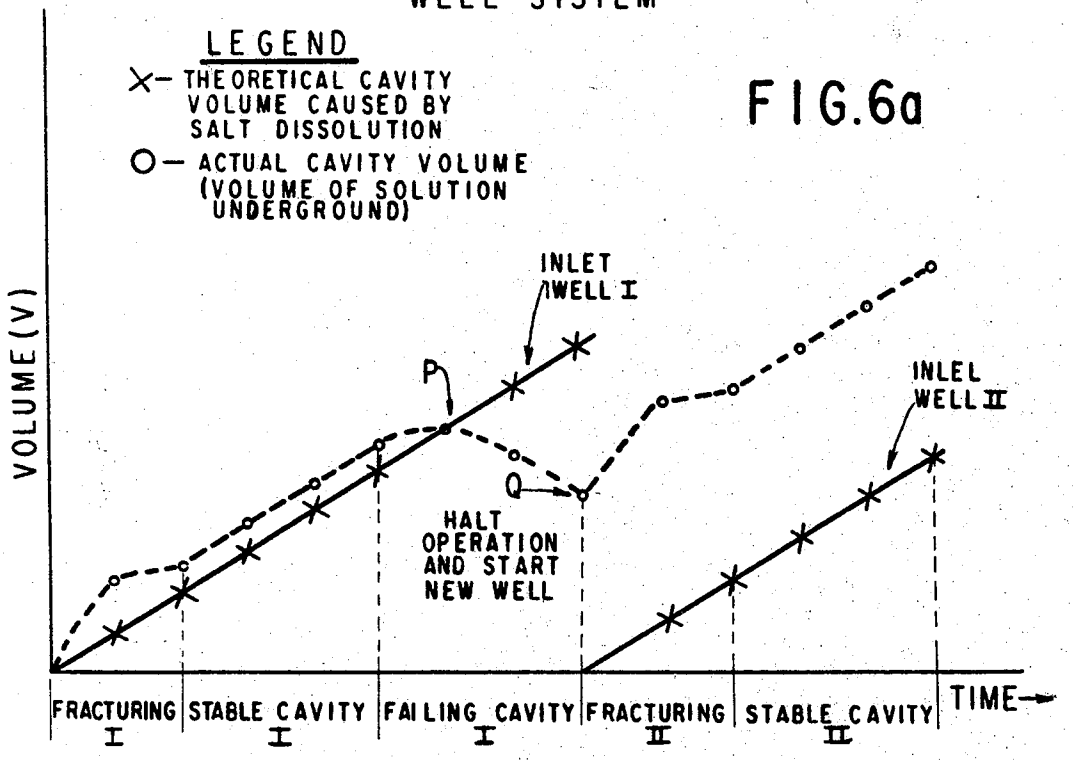
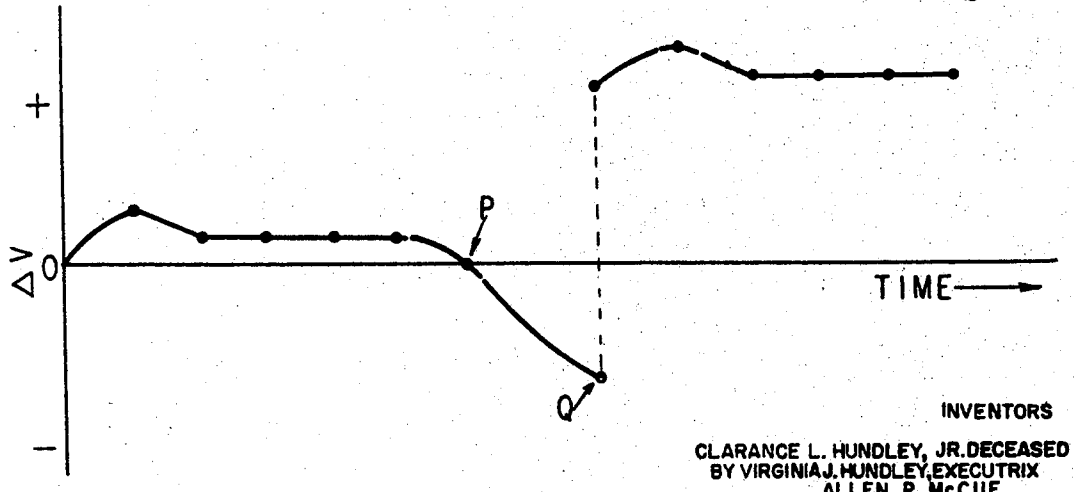


FIG. 6b



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PROCESS OF UNDERGROUND SALT RECOVERY

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Filed Feb. 21, 1966, Ser. No. 530,766

17 Claims. (Cl. 299—4)

ABSTRACT OF THE DISCLOSURE

A method of solution mining of salts and mineral deposits, which comprises the use of one or more input wells for the solvent and one or more output wells in which only substantially saturated solution is removed from the output wells to avoid caving around the output wells and a method of determining when new input wells should be opened to prevent caving or subsidence around an output well.

This invention relates to a method of solution mining for use in removing salts and mineral deposits from underground formations by the use of solvents. The term "salt" is used in a generic sense to include not only sodium chloride but other soluble salts such as, for example, sodium nitrate, ($NaNO_3$), potassium chloride, (KCl), epsom salts, ($MgSO_4.7H_2O$), kiersite, ($MgSO_4.H_2O$), calcium chloride, ($CaCl_2$), trona, ($Na_2CO_3.NaHCO_32H_2O$), and other salts, and also to include the mining of sulfur by hot solution melting methods and the removal of mineral ores by solution or solvent mining.

For many years, salt has been extracted from underground formations by circulating a solvent through a single well cavity, into the salt bed, either down the casing and out through the tubing or vice versa. Occasionally, two wells in a salt formation would interconnect by dissolving out salt over a sufficient lateral area for one well to communicate with the other. This process usually took a year or so of solution operation to produce such an interconnecting gallery. To produce such an interconnecting gallery in a reasonable time only dilute brine could be removed from the well or wells because of the lack of dissolving surface. To produce such an interconnecting gallery with the removal of substantially saturated brine would require many years.

The percentage of salt recovery by either single well or multiple wel extraction was never satisfactory because in single well operation, a morning-glory cavity was formed and in multiple wells, the connection, as a rule, was formed at the top of two or more single wells where a morning-glory pattern would spread out and interconnect with the adjacent well. In the morning-glory cavities, insoluble materials, caving from the roof or depositing from the brine solution, blanket the floor of the cavity and impede or prevent further solution of salt from the sidewalls and top of the morning-glory and roof caving is encouraged by the lateral spread of the cavity.

The development of solution mining, by the use of wells connected by hydraulically fracturing near the base of

the salt formation prior to 1960 is described in an article entitled, "Solution Extraction of Salt Wells Connected by Hydraulic Fracture," by Bays, Peters and Pullen, published in the Journal of the American Institute of Mining, Metallurgical and Petroleum Engineers, vol. 217, pages 266 to 277.

In the normal process of connecting wells, either by dissolving through from one well to the other or by connecting two or more wells by hydraulic fracturing, substantial difficulties have been encountered through caving of the roof of the wells due to the removal of the supporting salt structure and this has led to serious problems of subsidence of the earth above the well, or wells, and also to the breaking of well casings, which in many instances necessitated the abandonment of one or more producing, single, or interconnected sets of wells.

The term subsidence is used to refer to surface movement which is directly related to underground movement. This invention, by preventing or reducing underground movement, prevents or reduces surface movement or subsidence. Because of varying strengths of beds between the salt beds and the surface at different locations, the subsurface movement which can be tolerated with little or no surface effect will vary from location to location.

It is an object of the present invention to prevent or reduce subsidence of the earth formation above solution mining cavities or to confine the subsidence to areas where it is of minor economic importance.

Another object of the invention is to permit extraction of salt and other solution recoverable minerals farther and farther away from the processing plant or the recovered brine storage area without interfering with the production from the wells nearest the plant or recovered brine storage area or interfering with the piping of the concentrated salt or other product solutions into the processing plant or storage area.

Another object of the invention is to increase the recovery of salt from a given area where morning glorying and the resulting caving often force complete abandonment of a given area before a major fraction of the salt is recovered.

Another object of the invention is to reduce the subsidence and prevent breakage of well casings in producing wells while bringing into operation input wells farther and farther removed from the producing wells.

Another object of the invention is to extend the life and area of a solution mining system without interruption of production from the producing well area.

Various other objects and advantages of the invention will appear as this description proceeds.

Some of the problems encountered in solution mining of brine fields are described in the U.S. patent to Jacoby, No. 3,012,764 granted Dec. 12, 1961, particularly in column 1, lines 8 to 53, but the problems discussed in the said patent are not adequately solved by the method described and claimed therein.

In the accompanying drawings,

FIG. 1 illustrates a solution mining cavity around a single well in which the solvent has been introduced through the casing adjacent the top of the well, and removed through tubing adjacent the bottom of the well.

FIG. 2 illustrates a solution mining cavity for a single well formed when the solution is introduced through tub-

ing at or near the bottom of the formation and removed from the casing near the top.

FIG. 3 illustrates a solution mining field development in which a well has been connected to a cavity by hydraulic fracturing.

FIG. 4 illustrates in diagrammatic plan view the development and extension of a solution mining field in such a manner as to eliminate or significantly reduce subsidence and to permit further development of the mining area without interfering materially with production from the producing well or wells.

FIGS. 5*a* and 5*b* are graphs showing one method of determining when it is desirable to abandon or cease using one inlet well and start a new inlet well in a single or multiple well system not then fracture connected to avoid further caving around the old inlet well, and

FIGS. 6*a* and 6*b* are graphs showing one method of determining when it is desirable to abandon or cease using a given inlet well and start using a new inlet well in a fracture connected well system to avoid further caving around the inlet well previously used.

With the development of the technique of connecting wells by hydraulic fracturing between wells as described in the said publication of Bays, Peters and Pullen, it became possible to interconnect wells, or wells and solution mining cavities over substantial distances, adjacent the bottom of a salt or other solution recoverable bed, so that more of the salt or other soluble mineral could be recovered from the underground formation with reference to the percentage of underground salt available and to interconnect wells and produce saturated solution therefrom within a much shorter time than previously possible under the old methods of interconnecting wells by solution from around each well. However, caving of the roof of the cavities, subsidence of the ground above the cavities and loss of wells due to bending, breaking or clogging of the well casings continued to plague the industry.

In the application of hydraulic fracturing for salt or other solution mineral recovery, an existing well or existing well system or gallery was fractured into from a distant point, and solution of the formation took place usually by pumping the solvent into the old well or gallery and recovering it from the newly connected well or wells. By operating in this manner, dissolution of salt in the vicinity of the production well was avoided, thus making a stable situation at the production well.

In this process, however, the solvent or dilute solution of the salt or other mineral to be recovered was pumped into the old well or gallery and exerted most of its dissolving action on the walls and adjacent the top of the old well or gallery thereby increasing the area of unsupported roof, which eventually caved and caused subsidence running all the way to the surface and in many instances, caused collapse or stoppage of the casing or tubing going into the old well, eventually forcing abandonment of the old well or gallery, and preventing further recovery of salt in the area of the old well or gallery which necessitated the opening of a new solution field. In some instances where solution took place at the top of the wells, the morning-glory around one well would extend to and connect with the producing well, thereby increasing the area of unsupported roof structure and causing caving which caused failure of the production well.

Our invention overcomes all of these problems. In following the method of our invention, an existing well system consisting of a single or multiple well, may serve as the target for the hydraulic fracturing operation and after the initial well or gallery is prepared as a target, a new well or wells are drilled some distance away from the target well or gallery and the formation fractured from the newly drilled well back into the existing wells or galleries. The order in which the wells are drilled and hydraulically fractured is unimportant as long as the flow of solvent is from the planned input well to the planned output well or wells. However, instead of circulating the solvent or dilute brine from the old well or gallery into the new well, and removing the concentrated brine from the new well, one of the features of our invention includes introducing the solvent or dilute brine into the newly fractured or remote well, and circulating it through the fracture to the old gallery or wells, so that the solvent or dilute brine becomes saturated before reaching the old well or gallery of wells. Only saturated solution is thereby introduced into and removed from the old well or gallery of wells, and no further soution takes place along the side walls or top of the old well or gallery of wells. The roof support of the old well or gallery remains the same as it was before the new well was drilled and connected to the old formation and no further caving, subsidence or damage to the old wells can take place. Because only saturated brine enters the old well or gallery, it is possible to take the saturated solution from the old well or gallery adjacent the top thereof, so that insoluble materials may drop out of the saturated brine solution in the old wells; however, the saturated solution may be removed from any desired level of the old wells.

The application of our method is illustrated in FIGS. 1, 2, 3 and 4. The well or wells to be used as the target for hydraulic fracturing may be developed in any desired manner. In FIG. 1, the well has been developed by drilling into the formation, introducing the solvent through the outer casing **1** adjacent the top of the salt and removing the concentrated solution or brine from the inner tubing **2** which extends to a point adjacent the bottom of the salt. In this method of developing a target well, the well A develops a morning-glory pattern illustrated at **3** in which the dilute solution or solvent has spread out along the top of the salt bed adjacent the insoluble roof; the concentrated solution being heavier has been removed from adjacent the bottom of the well. In this morning-glory type of well development, the unsupported roof spread becomes greater and greater the farther the morning-glory is extended, and when the roof caves or when particles of insolubles drop from the roof structure or the brine, they tend to blanket the lower areas **4** of the morning-glory, so there is less dissolving of salt from the lower areas, and the extension of the morning-glory pattern becomes greater and greater, thus aggravating the problem of roof caving and subsidence and casing failures. However, in the method of our invention, the extension of the morning-glory pattern is limited to a safe distance which will provide good roof support. This safe distance will vary from location to location because of different overlying formations and different depths.

FIG. 2 illustrates another type of target well development in which the solvent or dilute solution has been introduced through the tubing **2***a* and removed through the casing **1***a*. In this type of well development, the cavity around the wells tends to develop in a more cylindrical or barrel-like shape as indicated by the outlines **5**. The dissolving takes place at a nearly uniform rate from top to bottom of the cavity as solvent is introduced through tubing string **2***a* adjacent the bottom of the cavity where it mixes with the brine already in the cavity. Saturated brine is forced out of the cavity and up through casing **1***a*. The unsupported roof area is smaller in diameter than in the morning-glory pattern of FIG. 1, and there is less tendency toward the development of caving. The development of a cavity and the production of brine will be at a lower rate when this method is used. However, a more stable cavity is formed and the recovery of salt under the cavity is nearly complete, approaching 100 percent. Recovery of salt from a morning-glory cavity is only about one-third, as at least two-thirds of the salt remains under the inverted cone or morning-glory cavity shown in FIG. 1.

As illustrated in FIG. 3, a target well or well gallery D, which may correspond either to the shape of well A

or well B of FIG. 1 or FIG. 2, has first been developed and well C has been drilled some distance away from target D and the formation fractured adjacent the bottom of well C so as to interconnect well C with target D. A cavity C' may be formed at the bottom of well C if desired.

After the hydraulic fracture and wash-through period between well C and the target well or well gallery D which produces a low pressure connection between well C and target well, the solvent or dilute brine solution is introduced through well C, the spacing between well C and wells A, B or D is such that a saturated solution is produced in passing from well C to wells A, B or D and only a saturated solution is removed from the target wells A, B or D, either through the casing **1**, **1***a*, **1***b* or the tubing **2**, **2***a*, **2***b* or both. As stated above, we prefer to remove the saturated solution adjacent the top of the target or producing wells A, B or D. However, it is necessary to remove the water or dilute brine from the target well before saturated brine can be produced.

By introducing the solvent or dilute brine solution through well C and providing sufficient length of travel between well C and wells A, B or D for the solution to become saturated, caving problems around wells A, B or D or any other target area, are substantially eliminated and if wells A, B or D, or a gallery of interconnected wells A, B or D are located adjacent the processing plant or brine storage area, only saturated solutions pass through the piping from wells A, B or D to the processing plant or storage area and new piping connections for the saturated solution going into the plant become unnecessary as new injection wells are added to the system.

In FIG. 4, a processing plant or storage area is indicated at **10**, the target or outlet wells A or B or a gallery of previously interconnected wells is indicated at **11**, the piping from the target or outlet well **11** to the plant or storage area is indicated at **12**, and the piping to the input well **14** is indicated by the line **13**. Further interconnected wells which may be formed and hydraulically fractured into the old wells or gallery are indicated at **15**, **16**, **17** and **18** merely to show the possibilities of extending and expanding the solution mining field without interference with the injection of water into well **14** and the production of brine from well **11**, or without danger of causing subsidence and caving around well **11**. The piping from well **11** into the plant or storage area may be insulated or heated to prevent precipitation, from the saturated or concentrated solutions in the piping from the outlet well to the plant. The piping **13** from the plant **10** to the well **14**, or to any other of the wells **15**, **16**, **17** or **18**, carrying the solvent or dilute brine need not be insulated or heated as the concentration of the solvent in the outgoing solution from the plant is usually below that at which danger of precipitation occurs. However, if water or a heated mother liquor is pumped through line **13** this line may be insulated to prevent heat loss and freezing or precipitation of salt therein.

As the new wells **15**, **16**, **17** and **18** are needed, they are drilled and fractured into the old formation and operation is started from the new wells, piping **13** from the plant or storage area **10** can be rearranged so as to flow into any of the newly drilled and interconnected wells while the piping **12** from the outlet well **11** can remain undisturbed and unchanged. The new piping into wells **15**, **16**, **17** and **18** is indicated by the dotted lines **13***a* and the hydraulically fractured underground connections between the new wells **15**, **16**, **17** and **18** is indicated by dash lines **19**. The outer circle around the wells **14**, **15**, **16**, **17** and **18** is intended to indicate the cavity or pool of brine around the base of these wells. These cavities will increase in size, as solution around wells **14**, **15**, **16**, **17** or **18** takes place, but the undissolved area between the wells will act as pillars to support the formation and experience as well as evidence of subsidence will enable the operators to judge how much salt may be removed and still leave sufficient pillar support to prevent material subsidence.

As the connections between the wells become enlarged and the cavity at the base of any of the inlet wells becomes enlarged, this provides a mixing bowl where the incoming solvent or dilute brine is promptly mixed with the solution at the inlet well.

Where the salt bed contains calcium sulfate, (anhydrite) special problems arise in the old method of introducing the solvent into the old well or gallery. The calcium sulfate is more soluble in a dilute brine than in a saturated brine so that when water is introduced near the top of an old solution mining cavity, the solution first dissolves calcium sulfate (anhydrite) which weakens beds near the top of the cavity containing calcium sulfate, thereby weakening the roof structure. As additional sodium chloride dissolves, the calcium sulfate precipitates. However, this precipitation does not take place readily so that the brine becomes supersaturated with reference to anhydrite or gypsum and if introduced immediately into pipe passages, pumps or other agitated passages, the super-saturation will be discharged and the anhydrite deposited in the pipes, pumps and so forth of the plant unless dilution water is added to prevent the precipitation. This, however, dilutes the brine solution with the result that processing of the brine is made more expensive. By introducing the solvent water or dilute solution into one of the wells **14**, **15**, **16**, **17** or **18**, any anhydrite or gypsum which is dissolved from the formation will have ample opportunity to precipitate within the formation before it reaches the target or outlet well **11**, so that no further weakening of the roof of well **11** occurs, and no precipitation of anhydrite or gypsum in the line **12** going into the plant or lines and pumps within the plant is likely to occur, making it unnecessary to add dilution water to the product brine.

Furthermore, by introducing the water or dilute solvent into the bottom of the input well or wells where it quickly mixes with the pool of concentrated salt or other solution in the bottom of the input well or wells or in the passage between the input well or wells and the output well, the solution quickly becomes saturated with sodium chloride, for example, and will not dissolve calcium sulfate to the same extent, so that caving within the connected passages, other than that produced by dissolution of the salt therefrom, does not occur. The introduction of water at the bottom of the input well or wells and the resultant mixing, causes uniform dissolution of the salt, thus making a cylindrical or barrel shaped cavity.

The space between well C and wells A or B must be 200 feet, it is preferably 500 feet or more from the edge of the cavity around the target well or gallery. Spacing of 600 to 1200 feet between wells to be connected by hydraulic fracturing is preferred but connections have been made by hydraulic fracturing at a depth of about 6400 feet between wells spaced about 2600 feet apart. The fracture is preferably made adjacent the bottom of the mineral bed to be removed at whatever depth this may occur.

Where the target cavity is made by top injection of water and bottom withdrawal of brine (well A), it has been found that the cavity top enlarges at the rate of about 1 foot per day, thus the approximate edge of such an existing cavity may be determined.

Before using the target well as an output well, it is desirable to bleed off any dilute solution remaining in the well by pumping or otherwise removing the dilute solution therefrom. This may be done most conveniently by removing the brine from a well which is open to the upper portion of the target cavity. The dilute brine so withdrawn may be used for make-up to an injection well. After this has been done only substantially saturated solution is removed from the target or output well.

Theoretically, and under stable conditions, the actual size of the underground cavity should increase in a given time by the volume amount of salt dissolved in said time. However, when caving or subsidence begins in the underground formation, the actual size of the underground cavity no longer increases by the volume amount of salt dissolved.

By knowing the actual size of the underground cavity in relation to the theoretical size that the cavity should be, because of salt dissolution, it is possible to recognize when the cavity begins to diminish in size due to caving and/or subsidence before the caving and/or subsidence is physically evident at the surface and steps may be taken to stop the injection into one inlet well and start injection into another inlet well to stabilize and prevent further caving adjacent said first inlet well.

The measurement of both the actual cavity size and the theoretical cavity size due to salt dissolution depends upon the particular solvent-salt system being utilized.

By measuring the amount and concentration of solvent pumped into a solution mine formation, and the amount and concentration of recovered solution and calculating the amount of salt dissolved, it is possible to calculate with a close degree of accuracy the actual size of the underground cavity at a given time, as well as the theoretical cavity due to salt dissolution.

If the actual size of the cavity starts to decrease in relationship to the size that it theoretically should be due to salt dissolution, this may be attributed to caving and/or subsidence and at such time steps may be taken to halt injection in one well and start injection into another well.

The actual cavity size is equal to the volume of solution underground at a given time, and includes the unrecovered fracturing solution in addition to the solution remaining in the dissolved cavity. The actual cavity size (volume) is determined by the net result of the salt dissolving and the fracturing and any subsidence which may occur.

FIGS. *5a, 5b, 6a* and *6b* show graphically one method of determining when it is desirable to move injection from one inlet well and start operation from another inlet well, with reference to a sodium chloride brine recovery operation. Similar conditions apply in all solution mining systems.

FIGS. *5a* and *5b* show typical performance for a single well or multiple well system where no fracturing is used. The theoretical cavity volume created by salt dissolution, and the actual cavity volume remain the same until closure of the cavity starts, as a result of caving, subsidence or the like. The point P at which the theoretical cavity volume begins to exceed the actual cavity volume shows that some caving or closing of the cavity has occurred. As the cavity closes, brine is forced from the cavity, causing the actual cavity volume to be less than the theoretical volume of the cavity created by salt dissolving. The theoretical cavity volume is no longer equal to the actual cavity volume after the caving or subsidence starts. The actual cavity volume at a given time is equal to the volume of solution underground. FIG. *5a* shows theoretical cavity volume and the actual cavity volume (solution underground) versus time and FIG. *5b* shows delta V (ΔV) versus time.

FIGS. *6a* and *6b* show typical performance for a fracture connected system. These graphs illustrate how both theoretical cavity volume created by salt dissolution and solution underground (actual cavity volume) are used to determine when it is desirable to stop injection into one well and hydraulically fracture and start injection into another well and use the old well or gallery as the output well. The point P indicates when the caving or subsidence started and the point Q indicates when a new well II has been fractured and put into operation as an injection well. During the periods of substantially stable cavity operation, the actual cavity volume runs parallel to the theoretical cavity volume caused by salt dissolution. During the period that cavity I is in operation as an inlet well and prior to any caving or subsidence the actual cavity volume is greater than the theoretical volume caused by salt dissolution because part of the actual cavity has been caused by fracturing. After well II has been put into operation the actual underground cavity includes the cavity of old well I as well as the cavity of new well II. However, as salt is no longer being dissolved at the cavity of old well I, a new theoretical cavity line for well II has been drawn. As with well I, the actual cavity volume of well II begins to parallel the theoretical cavity volume soon after fracturing. During the fracturing and wash-in period of wells connected by hydraulic fracturing the solution underground rapidly increases as solution is pumped into the formation to extend the fracture. A portion of this solution is not recovered for some time.

For the purpose of clarity, FIGS. *6a* and *6b* show that injection into well I is stopped before injection into well II is started. In actual practice, however, injection into well I would continue until the fracturing of well II is completed and well II is ready for use as an injection well.

FIG. *6b* shows that by plotting ΔV (actual cavity volume minus the theoretical cavity volume) against time and noting when ΔV begins to drop (i.e. when solution is forced out of the cavity by caving), the beginning of caving can be determined. In FIGS. *6a* and *6b*, point Q, show what happens when a new well is fractured into the old cavity and the old cavity used as the outlet well. The volume of solution underground first begins to increase rapidly with reference to the theoretical cavity volume as the fracture of the new well is extended, then levels off and begins to increase parallel to the theoretical cavity volume.

Instead of determining the cavity volume as described in connection with FIGS. *5a, 5b, 6a* and *6b*, other methods of determining the beginning of subsidence may be used, such as by comparison of surveyors bench marks or merely noting brine flow from the cavity in excess of the rate of water or solvent input. In some instances it may be of advantage to have a new input well drilled and hydraulically fractured into the old well cavity and to maintain this well capped or sealed and in reserve until evidence of caving or subsidence in the old injection well cavity begins to show and to then put the new reserve well promptly into operation as the new input well for the system. It is preferable, however, to put the new input well into operation as soon as evidence of caving or subsidence becomes apparent in the old injection well. The margin of maximum extraction with safety against caving can be judged by calculation and previous experience in a given solution mining field.

From the above discussion it is apparent that by determining the volume amount of salt dissolved and the volume amount of solution underground it is possible to determine when caving and/or subsidence occurs and hence when injection into a new inlet well should be started.

Example I

This example demonstrates the method of determining caving and/or subsidence with a sodium chloride-water system at 25° C., wherein:

I equals the volume of water injected
B equals the volume of brine produced
C equals the theoretical cavity volume (produced by salt dissolution)
S equals the actual cavity volume or the volume of solution underground.

The system is generally operated, for maximum efficiency, so that a saturated brine solution is withdrawn. However, the system may be operated at withdrawal concentrations other than of saturation.

The following are typical calculations when the brine is saturated and at a temperature of 25° C.

The values I and B may be readily determined from surface measurements.

At 25° C., 0.169 [1] volume of salt dissolved in one volume of water. For I volume of water injected, this will dissolve 0.169 I volume of salt. Therefore

$$C=0.169\ I$$

At 25° C., 1.147 [1] volumes of brine will be produced from one volume of water. For I volumes of water injected, this will produce 1.147 I volumes of brine. Therefore

$$S=1.47\ I-B$$

Since $\Delta V=S-C$ then,

$$\Delta V=1.147\ I-B-0.169\ I$$
$$\Delta V=0.978\ I-B$$

By plotting ΔV versus time and noting when ΔV starts to decline sharply, it is possible to determine when caving or subsidence occurs.

It is not necessary to know the entire history of a solution mining operation to make use of the principles of our invention. The calculations illustrating one application of the invention according to Example I may be made for an operating solution mine, starting at any time. Although the true theoretical cavity volume and the true actual cavity volume may not be known, values may be calculated, starting at the time measurements begin, which will show if the cavity is stable or if subsidence has already started or is continuing. These values may be used to determine when it is desirable to start using a new input well to stabilize the formed solution mining cavity.

The steps set forth in the claims may be practiced in different order within the scope of our invention. Thus it is immaterial whether the target well or wells are formed first, or the input well is formed first, if the flow is from the input well or wells to the target well or wells. The new well may be drilled and ready to be fractured and put into operation, or drilled, and fractured into the output well before evidence of failure around the output wells begins to be noticeable.

Other methods of utilizing our invention than those specifically described herein will be obvious to persons skilled in the art and are intended to be included within the scope of the following claims.

We claim:

1. The method of solution mining which comprises opening an output well in a target area within a solution mining field enlarging the cavity around the output well by dissolving a portion of the soluble formation around said output well, hydraulically fracturing the formation from a well spaced a substantial distance from the enlarged output well to connect the said spaced well with the enlarged output well and provide sufficient spacing therebetween to produce a substantially saturated solution at the output well using the spaced well as an input well, and circulating a solvent solution to the spaced well and through the formation to the enlarged output well to introduce into and remove from the output well only substantially saturated solutions of the mineral being mined.

2. The method of claim 1 in which the output well is connected to a processing plant.

3. The method of claim 1 in which the output well is connected to a processing plant and the solvent solution is returned to the spaced well from a processing plant.

4. The method of claim 1 in which the solvent solution is introduced into the mineral formation through the spaced input well at a point adjacent to the bottom of the mineral formation and substantially below the top of the said mineral formation.

5. The method of claim 1 in which the solution mining field is a salt formation.

6. The method of claim 1 in which any dilute solution in a new output well is removed before producing substantially saturated solution from the new output well from a fracture connected input well.

7. The method of claim 1 in which the cavity around the output well is stabilized by introducing the solvent into a well spaced from the output well and dissolving sufficient of the salt formation to form a substantially saturated solution before reaching the output well and maintaining a substantially saturated solution in the output well cavity.

8. The method of claim 1 in which the flow of solvent into the input well is regulated so that only a substantially saturated solution is removed from the output well.

9. The method of claim 1 in which the solution mining field is enlarged by drilling additional wells spaced from the original input and output wells, hydraulically fracturing the additional wells into the mining field of the original input and output wells and flowing solvent into the additional wells at a rate which provides only substantially saturated solution in the original input and output well acavities and removing substantially saturated solution from a well in the original input and output well cavities.

10. The method of operating a well system for the recovery of mineral values by in situ underground solution thereof, which comprises flowing a dissolving liquid down one well, through the formation, and out of another well to dissolve a portion of the formation around each of said wells, drilling a new well into the formation spaced a substantial distance from the old well cavities and hydraulically connecting the new well to the old well cavities around said original wells and flowing the dissolving liquid down the new well, through the formation and out of one or more of the old wells and removing a substantially saturated solution from one or more of the old wells to reduce subsidence around the old wells.

11. The method of claim 10 in which the volume of dissolving liquid flowed down the new well and through the formation and into the old well cavities is such as to maintain a substantially saturated solution in the old well cavities.

12. The method of claim 10 in which the flowing of the dissolving liquid down the new well and out of one or more of the old wells is begun when caving and subsidence in the old wells begins.

13. The method of claim 12 in which the beginning of caving and subsidence is determined by a decrease in the amount of solution underground with reference to the calculated underground cavity volume.

14. The method of claim 1 in which the hydraulic fracturing from the spaced well is performed prior to any subsidence of the formation above the enlarged cavity around an output well.

15. The method of claim 1 in which the input well is opened first and the output well is opened later and in which an enlarged cavity is formed around the output well before recovery of a substantially saturated solution therefrom is begun.

16. The method of claim 10 in which the theoretical volume and the actual volume of the underground cavity beneath the wells is determined and when the theoretical volume begins to exceed the actual volume, indicating the beginning of subsidence, new input wells are drilled into the formation and hydraulically connected to the old well cavities and the dissolving liquid is flowed down the new input wells, through the formation and out of an old well, to provide only substantially saturated solution in the old well cavities and prevent further subsidence in the old well cavities.

17. The method of operating a solution mining field in which input and output wells are connected through the formation and a dissolving liquid is flowed down an input well, through the formation, and out of an output well and substantially saturated solution recovered from an output well, which comprises maintaining a record of the

[1] These values may be calculated from standard solubility tables for a saturated brine solution at 25° C.

theoretical underground cavity volume and of the actual underground cavity volume, and when the theoretical underground cavity volume begins to exceed the actual underground cavity volume, drilling new input wells into the formation and connecting them into the existing cavity by underground hydraulic fracturing and flowing the dissolving liquid down a new input well through the formation and out of a well in the old well cavities to provide only substantially saturated solution in the old well cavities and prevent further subsidence of the old well cavities.

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