

Feb. 27, 1962

C. T. BRANDT

3,022,986

METHOD FOR DEVELOPING CAVITIES IN SOLUBLE FORMATIONS

Filed Dec. 31, 1958

4 Sheets-Sheet 1

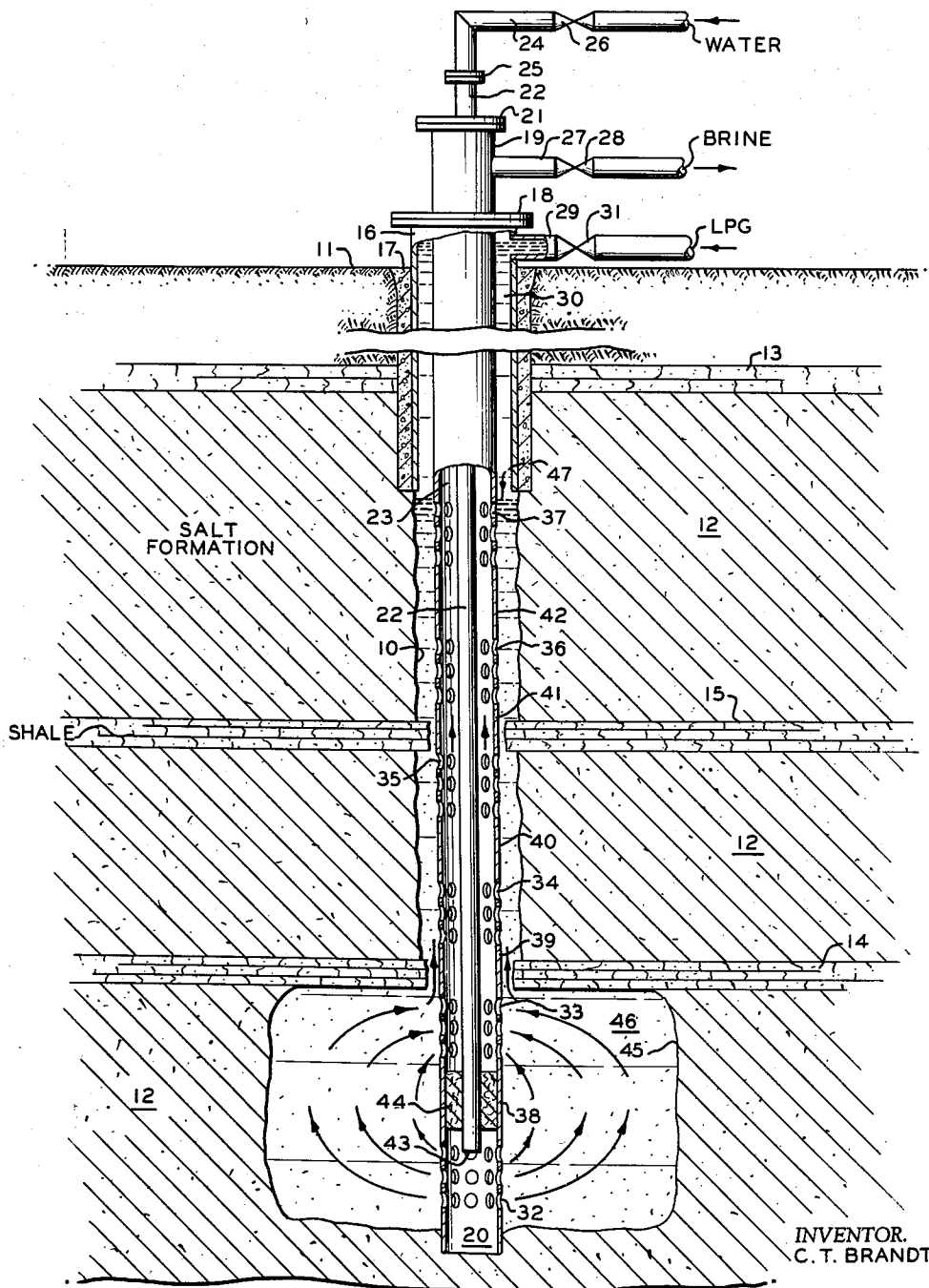


FIG. 1

BY

INVENTOR.
C. T. BRANDT

Hudson El Young
ATTORNEYS

Feb. 27, 1962

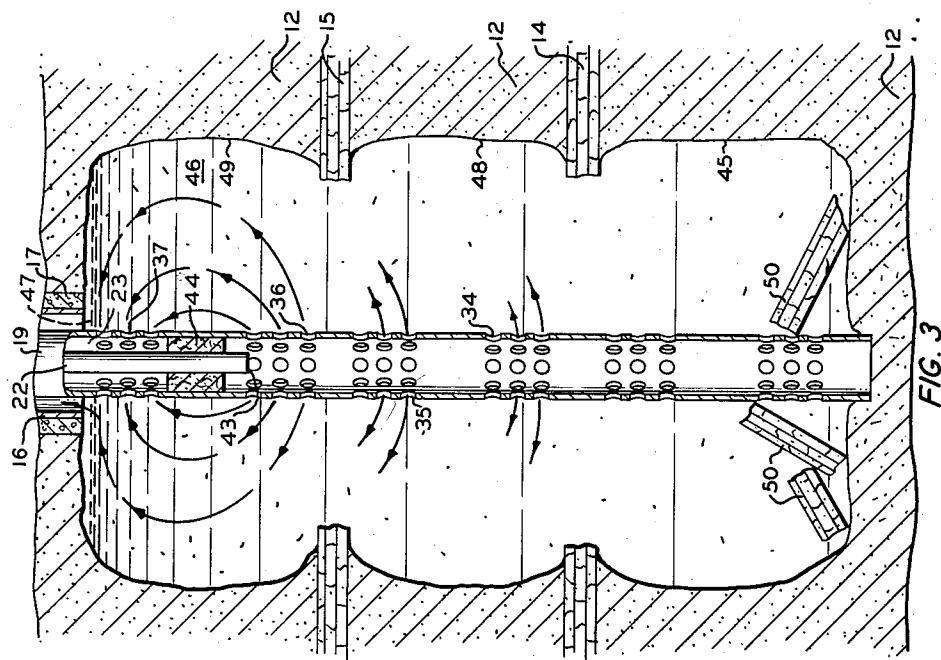
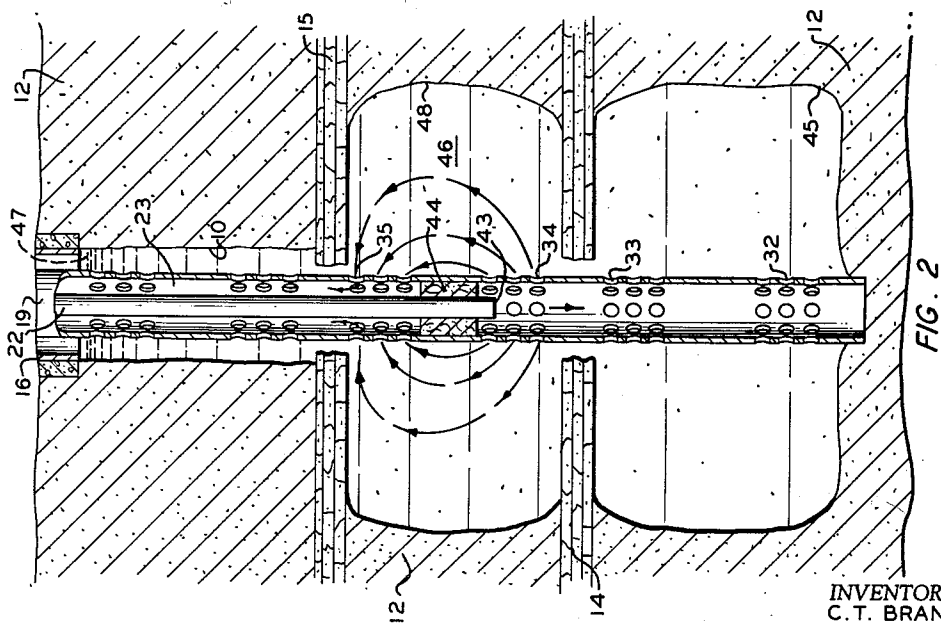
C. T. BRANDT

3,022,986

METHOD FOR DEVELOPING CAVITIES IN SOLUBLE FORMATIONS

Filed Dec. 31, 1958

4 Sheets-Sheet 2



INVENTOR.
C. T. BRANDT

BY

Hudson & Young

ATTORNEYS

Feb. 27, 1962

C. T. BRANDT

3,022,986

METHOD FOR DEVELOPING CAVITIES IN SOLUBLE FORMATIONS

Filed Dec. 31, 1958

4 Sheets-Sheet 3

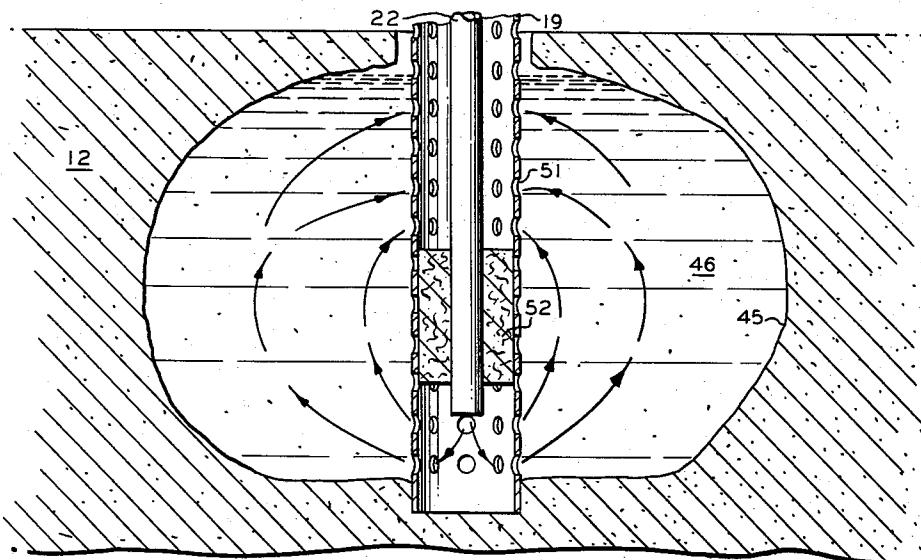


FIG. 4

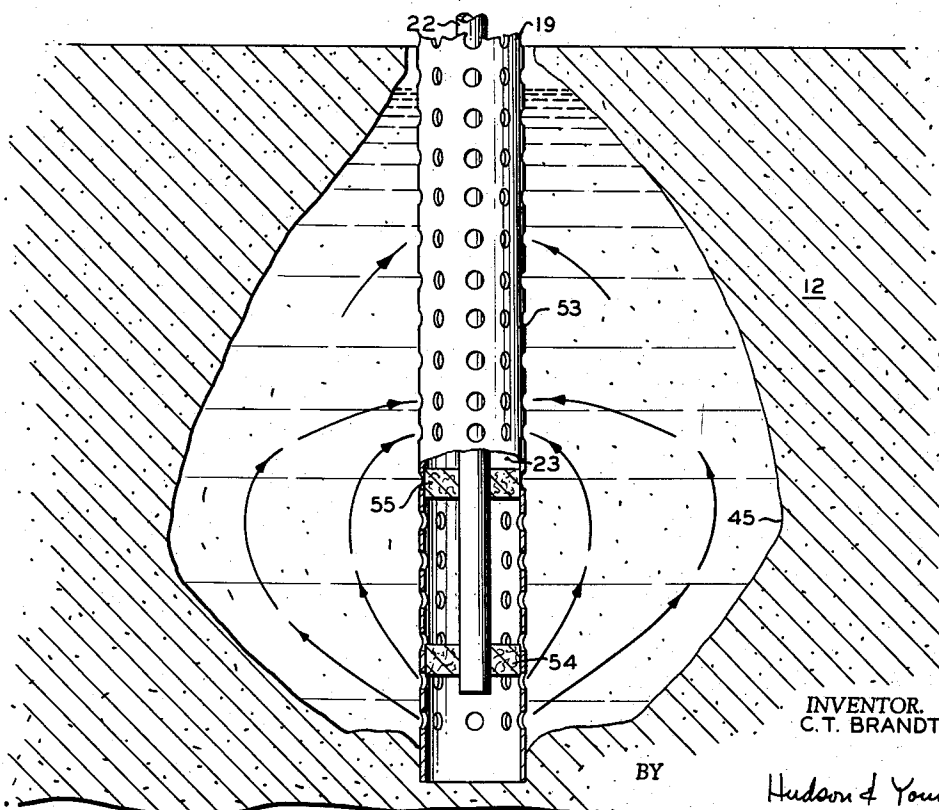


FIG. 5

INVENTOR.
C. T. BRANDT

BY

Hudson & Young

ATTORNEYS

Feb. 27, 1962

C. T. BRANDT

3,022,986

METHOD FOR DEVELOPING CAVITIES IN SOLUBLE FORMATIONS

Filed Dec. 31, 1958

4 Sheets-Sheet 4

FIG. 6

1

3,022,986

METHOD FOR DEVELOPING CAVITIES IN SOLUBLE FORMATIONS

Carl T. Brandt, Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware
Filed Dec. 31, 1958, Ser. No. 784,116
7 Claims. (Cl. 262-3)

This invention relates to the dissolution of soluble subterranean formations with a solvent. More particularly, the invention relates to a method of mining soluble salts in subterranean deposits for the recovery of the same and to form underground reservoirs for the storage of gases or liquids.

Soluble salts in subterranean deposits have been mined and underground reservoirs for the storage of gases and liquids have been formed by forcing a solvent into the formation of soluble material to dissolve a portion thereof and thereafter removing the solvent containing the dissolved soluble salt from the cavity thus formed. Usually the soluble subterranean deposit is salt and the solvent is water; however, reservoirs can be dissolved out of formations such as dolomite or limestone by using an acidic aqueous solution.

Usually the salt formations in which the reservoir is to be formed is covered with a layer of shale or anhydrite which is relatively insoluble. Very often, the salt formation contains relatively thin layers or stringers of either shale or anhydrite disposed at various elevations in the salt formation. Since these stringers are insoluble in the solvent, they present a considerable problem in the formation of a cavern of the desired shape and capacity.

It is usually desirable that the reservoir have a generally conical shape, more specifically the shape of a frustum of a cone, so that the roof of the reservoir slopes downwardly over a large area so as to reduce the collapse of the roof into the reservoir. If the cavern is to be constructed to a depth in the formation where there are one or more insoluble stringers, the dissolution of the soluble material usually occurs to a greater extent on one side of the insoluble stringer than on the other side, depending on where the solvent is introduced, because the insoluble stringer prevents fresh solvent from coming into contact with material to be dissolved. Therefore, in order to form a cavern having a desired shape, it is necessary to introduce the solvent on the opposite sides of the insoluble stringers.

It has been recognized in the art that the shape of the cavity dissolved from a soluble formation can be controlled by adjusting the elevation where the solvent is discharged into the formation. Thus, the cavity can be made larger in area at any particular elevation than at another elevation by continuing the dissolving action through the introduction of solvent at that particular elevation for a longer period of time and then either raising or lowering the discharge end of the solvent inlet pipe when the desired diameter has been reached for that particular elevation. Unfortunately, where dissolution of the salt has been occurring below the nonsoluble stringer, there is danger that a portion of the nonsoluble stringer will break off because of the washing action occurring immediately below and falling to the bottom of the cavity thereby binding the solvent inlet pipe and preventing its removal. This is an even greater problem where there are several nonsoluble stringers in the salt formation because one of the upper overhanging ledges of insoluble material may break off and drop onto a lower insoluble stringer and bind the solvent string in the hole through the lower insoluble stringer.

Where there are insoluble stringers in a formation in which a cavern of the desired shape has been formed, it is sometimes impossible to utilize the full volume of

2

the cavity for the storage of gases and liquids because the displacement tubing for the removal of the stored material cannot be placed into the bottom of the cavity. Thus, after the wash string has been removed, it may be impossible to rethread the displacement tubing through the hole in the insoluble stringer located within the cavity volume so that the volume between the bottom of the tubing and the bottom of the cavern represents unuseable storage space. Also, where the displacement tubing has been successfully lowered through the insoluble stringer into the bottom of the cavity, portions of the insoluble stringer sometimes break off and drop into the bottom of the cavity in such a manner as to bend the displacement tubing and reduce the rate of withdrawal of stored material from the cavern. Also, it is impossible to utilize the full capacity of the cavern where portions of the insoluble stringers have broken off after withdrawal of the solvent string and before the lowering of the displacement tubing because of the accumulation of broken insoluble stringer material in the bottom of the cavern.

An object of this invention is to provide a method of forming cavities in subterranean soluble deposits in a manner permitting the utilization of the full capacity of the cavity formed for the storage of gases and liquids.

Another object of this invention is to provide a method for mining soluble salts in subterranean deposits to form cavities of a desired shape and size.

Another object of this invention is to provide a method of forming cavities in subterranean soluble deposits containing stringers of insoluble material in an improved manner.

Another object of this invention is to provide a method for regulating the level of solvent injection in the solution mining of a soluble subterranean deposit.

Other objects and advantages of this invention will be apparent to one skilled in the art upon studying this disclosure, including the attached drawings.

FIGURE 1 is an elevational cross-sectional view of an underground cavity being formed in a salt formation having insoluble stringers located therein.

FIGURES 2 and 3 are partial elevational cross-sectional views of the underground cavity being formed in FIGURE 1 showing later stages in the evolution of the cavity.

FIGURE 4 is a partial elevational view of a second embodiment of the protective casing and sealing means of the invention shown in FIGURE 1.

FIGURE 5 is a partial elevational cross-sectional view of a third embodiment of the protective casing and sealing means of the invention shown in FIGURE 1.

FIGURE 6 is a partial elevational cross-sectional view of a complete underground cavity formed through use of this invention showing the storage of liquefied petroleum gas therein.

Broadly, this invention provides a method and apparatus for the mining of soluble salts from a subterranean deposit to form a cavity for the storage of gases and liquids by adjusting a slide valve means to change the elevations for the introduction and withdrawal of solvent into the subterranean deposit from a fixed protective casing located within the deposit in order to govern the shape and the size of the cavity being formed without damage from cave-ins of insoluble material adjacent to and within the cavity.

In this invention, a protective casing which has been perforated in the section to be located in the subterranean deposit is lowered into a drilled hole extending at least through a portion of the deposit and fixed therein. The protective casing extends through any stringers of insoluble material, such as shale or anhydrite, which might exist in the deposit of soluble material. A washing string is lowered into the subterranean deposit through the protective casing and arranged to be adjusted vertically so that

3

the open end thereof can be located at various elevations within the subterranean deposit. A sealing means, such as a packer, swab cup, or pipe protector, is fixed to the wash string adjacent the open end thereof and arranged within the protective casing to prevent the direct flow of liquid between the open end of the wash string and the annulus existing between the wash string and the protective casing. The solvent can either be circulated into the deposit through the wash string, with the withdrawal of solvent containing dissolved material being through the annulus between the wash string and the protective casing, or the solvent can be introduced through the annulus between the wash string and the protective casing, with the solvent containing the dissolved material being removed through the wash string. Preferably, the solvent is introduced through the wash string and, in this operation, the solvent flows through the apertures in the protective casing located below the sealing means into the subterranean deposit. The solvent containing dissolved soluble material is then removed from the cavity formed through the apertures in the protective casing located above the sealing means and then through the annulus between the wash string and the protective casing. In a backwashing operation, the flow is reversed from this described flow.

In one embodiment of the invention, the protective casing has a plurality of apertures which are arranged in groups separated by short lengths of unperforated casing. In a second embodiment, the protective casing is perforated through a section corresponding to the approximate height of the cavity to be formed. In this embodiment, the distance between the apertures corresponding to the inlets and outlets for the flow of solvents is determined by the length of the sealing means employed within the casing. Thus, the flow of solvent can either be limited to a short distance by the use of a packer of short length or the path of flow can be increased by the use of a packer of increased length. Also, two small packers fixed apart from each other on the wash string can be used to give a wide separation between the inlet and outlet apertures.

A particular feature of this invention is the provision of a protective casing permanently fixed throughout the height of the cavity formed to permit the wash string and displacement tubing to be respectively withdrawn and introduced into the cavity free from damage caused by collapse of either the ceiling of the cavity or insoluble stringers located therein. Also, the protective casing of this invention permits the full capacity of the cavern to be utilized for the storage of gases and liquids therein since it permits displacement tubing to be readily rethreaded through insoluble stringers located within the cavity and permits the displacement tubing, including a submergible pump attached to the end thereof, to be lowered to a point adjacent the floor of the cavity, notwithstanding insoluble material which may have fallen into the bottom of the cavity.

Referring to FIGURE 1 of the drawings, well 10 is drilled from the earth's surface 11 into subterranean salt formation 12 to an elevation to correspond to the bottom of the desired cavern. Salt formation 12 is overlaid by shale formation 13 and has stringers 14 and 15 of shale located at different elevations within the body thereof. Permanent casing 16 of a diameter of 13½ inch O.D. extends from the earth's surface 11 into the upper part of salt formation 12 and is sealed fluid tight by cement 17. Permanent casing 16 is capped by flange 18. Protective casing 19 extends through flange 18 into well 10 a distance corresponding to the depth of hole 10 so that the bottom end 20 of protective casing 19 is placed in the bottom of well 10. Protective casing 19 had a diameter of 8½ inch O.D. and is capped by flange 21. Vertically adjustable wash string 22 extends through flange 21 into protective casing 19 to form annulus 23 therebetween. Conduit 24 for the flow of water or the solvent into wash

4

string 22 is attached to wash string 22 by flange 25. Valve 26 in conduit 24 provides for the adjustment of the flow of water through wash string 22. Conduit 27 attached to protective casing 19 provides an outlet for the flow of brine from annulus 23 with valve 28 in conduit 27 providing for regulation of that flow. Conduit 29 attached to permanent casing 16 provides for the introduction of a nonsolvent fluid, such as liquefied petroleum gas, into annulus 30 existing between protective casing 19 and permanent casing 16 with valve 31 in conduit 29 providing for regulation of flow.

Protective casing 19 is perforated throughout the section located within salt formation 12 with the apertures 32, 33, 34, 35, 36 and 37 separated by unperforated sections 38, 39, 40, 41 and 42.

Wash string 22, having a diameter of 4½ inch O.D., is equipped near open end 43 with packer 44 which engages the inner wall of protective casing 19 in such a manner as to prevent the flow of liquid out open end 43 of wash string 22 and directly up through annulus 23 existing between wash string 22 and protective casing 19.

In operation, water, as solvent, is introduced through conduit 24 into wash string 22 to flow out open end 43 of wash string 22 into the bottom end of protective casing 19. Wash string 22 has been positioned vertically within protective casing 19 with packer 44 placed between groups of perforations 32 and 33 in the unperforated section 38 of protective casing 19. The water flows from protective casing 19 through apertures 32 into contact with salt formation 12 to form a cavity 45 by dissolution of the salt in the water. The brine 46 within cavity 45 is withdrawn through apertures 33 in protective casing 19 at a point above packer 44 so as to provide a generally upward path of flow. The brine so withdrawn flows through annulus 23 and conduit 27 to be removed from the well. The introduction of water and the withdrawal of brine is continued for a period of time until cavity 45 has assumed the desired shape and size. Generally, the dissolution of the salt will occur only below insoluble stringer 14; however, depending upon the diameter of hole 10 existing through insoluble stringer 14, there may be some dissolution of salt above insoluble stringer 14 by the flow of water into contact with the salt located thereabove and withdrawn through apertures 34 and 35. The dissolution of salt from around the foot of permanent casing 16 is prevented by maintaining the level of nonsolvent 47 at an elevation below the bottom end of permanent casing 16.

Referring to FIGURE 2 of the drawings, wash string 22 is raised to a new elevation where packer 44 is located between groups of apertures 34 and 35 adjacent the unperforated section 40 of protective casing 19 when cavity 45 below insoluble stringer 44 has reached the shape and size desired. The circulation of water through wash string 22 and the removal of brine through annulus 23 is continued to form cavity 48 in salt formation 12 between stringers 14 and 15. The discharge of solvent from end 43 of wash string 22 is primarily through group of apertures 34 although there may be some flow of water through groups of apertures 33 and 32. The withdrawal of brine from cavity 48 is primarily through group of apertures 35 although there may be some withdrawal of brine through the apertures located above. By raising the elevation of the end of wash tube 22 to a point between stringers 14 and 15 it is possible to dissolve the salt 12 more uniformly from just above stringer 14 which would be out of the path of flow if the introduction of solvent had remained between groups of apertures 32 and 33. The introduction of solvent at this elevation is continued until cavity 48 has reached the shape and size desired.

Referring to FIGURE 3 of the drawings, open end 43 of wash string 22 has been raised to a higher elevation where packer 44 is situated between groups of apertures 37 and 36 adjacent the unperforated section 42 of casing 19. At this elevation, the path of flow of water

is primarily through the group of apertures 36 although there is some flow through groups of apertures 35 and 34. The withdrawal of brine into annulus 23 is through the group of apertures 37. Dissolution of salt information 12 from around the footing of permanent casing 16 is prevented by maintaining the level of the interface between the nonsolvent 47 and brine 46 at a point just below the foot of casing 16. During the washing operations, large pieces 50 of stringers 14 and 15 have broken off and fallen into the bottom of cavity 45 against protective casing 19. The collapsing of stringers 14 and 15 does not prevent the withdrawal of wash string 22 because of the presence of protective casing 19 within cavity 45.

In FIGURE 4 of the drawings is shown a second embodiment of this invention wherein protective casing 19 is continuously perforated with apertures 51 over the length of the section located within salt formation 12. Packer 52 isolates a portion of the lower apertures 51 from the remainder of the apertures 51 to provide a path of circulation for the flow of solvent through wash string 22 into contact with the salt in formation 12. The length of packer 52 is determined by the distance which it is desired to have each portion of apertures 51 separated. Ordinarily, in this embodiment, packer 52 will be constructed with an extra long length, such as, for example, 8 feet.

In FIGURE 5 of the drawings is shown another embodiment of the invention wherein protective casing 19 is continuously perforated over a substantial length thereof and separation of the inlet and outlet apertures 53 for the flow of solvent is established by packers 54 and 55 mounted a fixed distance apart on wash string 22. Although the apertures 53 located between packers 54 and 55 are open to flow, there is no flow through annulus 23 because of the placement of packers 54 and 55. In this embodiment, packers 54 and 55 can be of the conventional size or, if desired, can be constructed with extra long lengths since the distance separating apertures 53 serving as inlets and outlets is determined by the distance separating packers 54 and 55 mounted on wash string 22.

In FIGURE 6 of the drawings is shown a completed cavern 56 in salt formation 57 in which there are found insoluble stringers 58 and 59 of shale. The wash string has been replaced with displacement tubing 60 which is connected to conduit 24. Submersible pump 61 is attached to the lower end of displacement tubing 60 for pumping stored material 62 to the surface. The liquefied petroleum gas to be stored is introduced through conduit 27 and flows through annulus 23 into the cavern 56. Protective casing 19 which was used in the construction of the cavern remains in place and serves to protect displacement tubings 60 and pump 61 from damage by debris 63 which has broken off from stringer 59 and fallen onto stringer 58. If protective casing 19 has not been left in place after the completion of the cavity, debris 63 would have prevented lowering displacement tubing 60 to the bottom of cavity 56 and the portion of the cavity below stringer 58 would have been lost for the storage of the liquefied petroleum gas.

The arrangement of the apertures in the protective casing is not critical and depends to some extent on the geological formations encountered. Where the perforations are grouped together and separated by unperforated sections, the protective casing can be perforated at any suitable intervals such as from 0 to 10 feet, 20 to 40 feet, and 50 to 70 feet measured from the end of the casing. The size of the apertures can be readily determined by one skilled in the art possessing this specification.

Although this invention has been described with respect to forming cavities in rock salt formations, this invention is applicable to forming cavities in other soluble deposits such as limestone and dolomite. Other solvents may be used in addition to water, for example, acid hy-

drocarbon, ammonia or alcohol, depending upon the particular soluble material within which the cavity is to be formed.

Reasonable variation and modification are possible within the scope of the foregoing disclosure, drawings and the appended claims to the invention, the essence of which is that there have been provided a method and means for mining soluble salt from a subterranean deposit for forming an underground cavity for the storage of gases and liquids by adjusting the elevations for the introduction and withdrawal of solvent into said subterranean deposit from a fixed protective casing located within said deposit in order to govern the shape and size of the cavity being formed without damage from cave-ins of insoluble material into the cavity.

I claim:

1. A method of forming shaped underground reservoirs in soluble underground formations for storage therein of fluids, said method comprising drilling a well into said soluble underground formation, introducing a casing into said well into said soluble underground formation, said casing having a plurality of apertures in the wall thereof in the section of said casing located within said soluble underground formation, fixing said casing in said well, running a tubing string into said casing to a selected elevation above the lower end of said casing, said tubing string being in fluid sealing relation with said casing by a sealing means located adjacent the lower end of said tubing string, introducing solvent into said tubing string and passing the solvent through the lower open end of the tubing string and thence through apertures in said casing located below said sealing means into contact with said soluble formation to dissolve a portion thereof and form a reservoir, withdrawing into the annulus between said casing and said tubing string said solvent containing dissolved soluble material therein from said reservoir being formed through apertures in said casing located above said sealing means, removing said solvent containing dissolved soluble material therein from said annulus, changing the elevation of the end of said tubing string after a period in which a reservoir of predetermined shape has been formed, and continuing to introduce solvent, to withdraw solvent containing soluble material, and to change the elevation of said tubing string until the complete reservoir is formed.

2. A method of claim 1 wherein the elevation of said tubing string is progressively raised from a lowermost position.

3. A method of claim 1 wherein the elevation of the end of said tubing string is progressively lowered from an uppermost position.

4. A method of claim 1 wherein said underground formation is salt and said solvent is water.

5. A method of forming a shaped underground reservoir in a soluble underground formation for storage therein of fluids, said method comprising, in combination, drilling a well into said soluble underground formation, introducing a permanent casing into said well and fixing the same therein, introducing a protective casing within said permanent casing, the lower end of said protective casing depending within said soluble underground formation at an elevation deeper than the lower end of said permanent casing, said protective casing having a plurality of apertures in the wall thereof in the section of said protective casing located within said soluble formation, fixing said protective casing in said well, running a tubing string into said protective casing to a selected elevation above the lower end of said protective casing, said tubing string being in fluid sealing relation with said protective casing by sealing means located adjacent the lower end of said tubing string, introducing a non-solvent into said well and maintaining a column of said non-solvent in the annulus formed between said permanent casing and said protective casing to prevent the dissolution of said soluble formation

7

adjacent the lower end of said permanent casing, introducing solvent into said tubing string and passing the solvent through the lower open end thereof and thence through apertures located in said protective casing below said sealing means into contact with said soluble formation to dissolve a portion thereof and form a reservoir, withdrawing solvent containing dissolved soluble material into said protective casing above said sealing means through apertures in said protective casing, changing the elevation of the lower end of said tubing string after a period in which a reservoir of predetermined shape has been formed, occasionally reversing the circulation of said solvent and said solvent containing dissolved mixture to control the shape of said reservoir, and continuing to introduce solvent, to withdraw solvent containing material, and to change the elevation of the lower end of said

8

tubing string until the complete reservoir is formed.

6. The method of claim 5 wherein the elevation of the end of said tubing string is progressively raised from a lowermost position.

7. The method of claim 5 wherein the elevation of the end of said tubing string is progressively lowered from an uppermost position.

References Cited in the file of this patent

UNITED STATES PATENTS

1,293,902	Peters	Feb. 11, 1919
2,618,475	Butler	Nov. 18, 1952
2,784,954	Ilfrey	Mar. 12, 1957
2,787,455	Knappen	Apr. 2, 1957