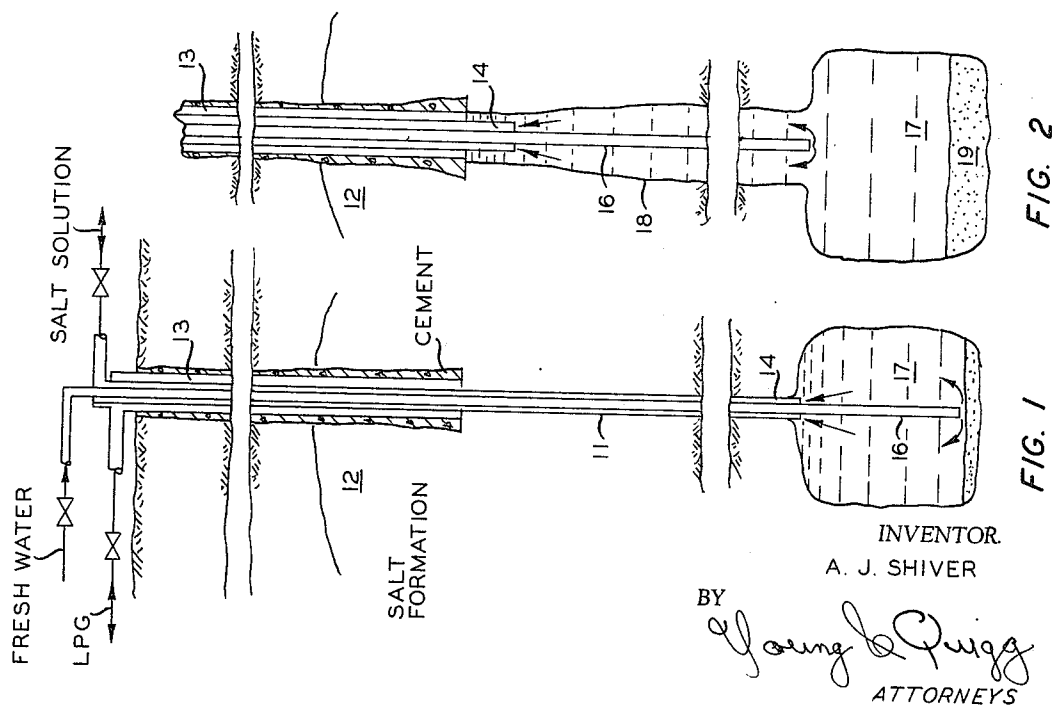


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UNDERGROUND STORAGE CAVERNS AND METHOD OF MAKING	AND OF STORING FLUIDS THEREIN	THE SAME
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2 Sheets-Sheet 1



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UNDERGROUND STORAGE CAVERNS AND METHOD OF MAKING THE SAME
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3,277,654

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2 Sheets-Sheet 2

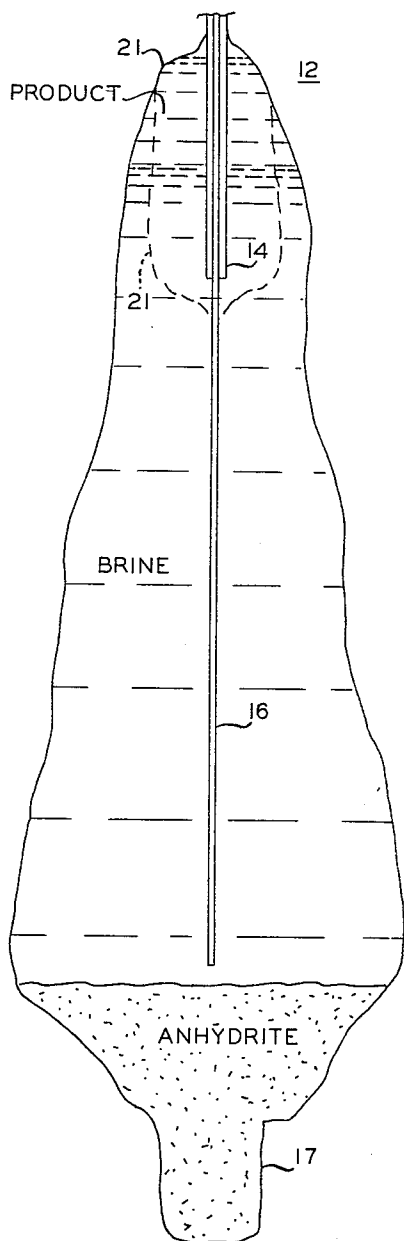


FIG. 6

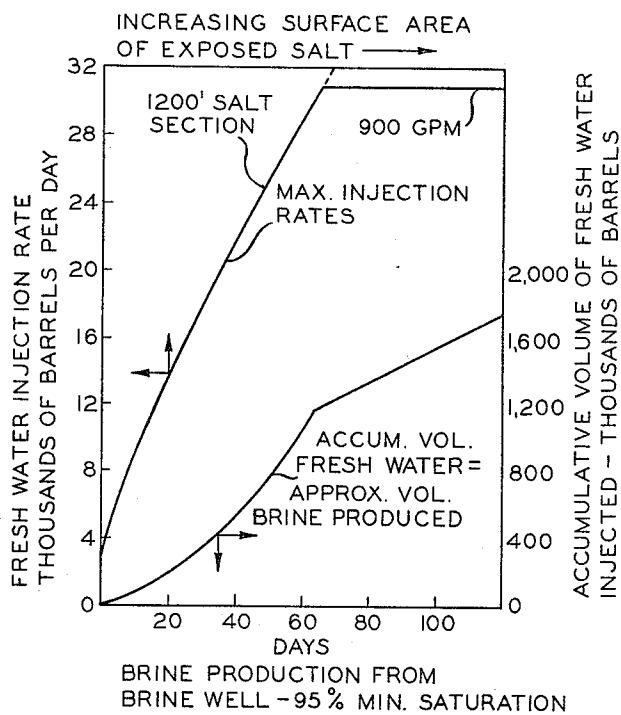


FIG. 5

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UNDERGROUND STORAGE CAVERNS AND METHOD OF MAKING THE SAME AND OF STORING FLUIDS THEREIN

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Filed Apr. 15, 1963, Ser. No. 272,912
8 Claims. (Cl. 61—5)

This invention relates to making underground storage caverns for water insoluble fluids and brine. In another aspect it relates to a novel method of and apparatus for operating dual chamber underground storage caverns wherein volatile hydrocarbon fluids are stored in large volumes and brine can be produced as required.

A perennial problem of petroleum refiners during the summer months is the storage of excess by-products which have no market, such as fuel oil, and liquefied petroleum gas such as liquefied propane, liquefied butane, and mixtures of the two. In an effort to alleviate this storage problem there has recently been developed a method for storing liquefied petroleum products in underground storage caverns formed by drilling to a salt formation and dissolving out a portion of the salt to form a cavern. This method has great potential in view of the cost of materials, such as steel. The advantages of underground storage over above-ground storage include: (1) lower costs, both initial and maintenance (underground storage has been estimated to cost as little as one-thirtieth the cost of steel tankage); (2) savings in ground space; (3) savings in the use of steel; (4) elimination of above-ground operational hazards; and (5) bomb proof protection for liquefied petroleum gas mixtures.

Saturated salt solutions have wide spread and voluminous use in the field in well drilling operations, and as a displacing fluid in underground storage of hydrocarbons. Economics of transportation dictate that the large amounts of brine be made near the site of their intended use. It has long been commonplace to drill into soluble salt formations and produce the required brine by solution mining, as shown in U.S. Patent 1,960,932, filed July 21, 1933. Additionally it is known that an underground cavity for light hydrocarbon storage can be solution mined by observing special precautions during formation, as taught in U.S. Patent 2,994,200, issued August 1, 1961.

It has been the practice to solution mine one bore hole to provide brine and to solution mine a separate bore hole to form a hydrocarbon storage cavern. The two caverns when formed separately can and have cost on the order of \$150,000–\$200,000 each. Moreover, the salt dome to be used may be of such horizontal dimension limitations that a space problem is created if separate brine wells are developed to the detriment of creating additional hydrocarbon storage caverns.

It is, therefore, an object of this invention to provide a method of making a dual purpose underground storage cavern.

It is another object of this invention to substantially reduce the cost of forming underground storage caverns for storing hydrocarbons and producing brine in the field.

It is still another object to conserve space in a salt dome for the formation of an optimum number of storage caverns as desired.

It is yet a further object to drill a single well into a salt formation and form two caverns therefrom, one for storage of water-insoluble fluids, and the other for brine production.

Further aspects, objects and advantages of the invention will become apparent from a study of the appended claims and the drawings, in which:

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FIGURE 1 is a vertical cross-sectional view partly in elevation showing the dual purpose cavern in the initial stages of formation of the lower chamber;

FIGURE 2 is a similar view of the same cavern during enlargement of the bore hole;

FIGURE 3 is a later view of the cavern nearing completion of the upper hydrocarbon storage chamber;

FIGURE 4 is a final view of the formation of the dual chamber cavern storing LPG in the upper cavern and commencing brine production from the lower cavern;

FIGURE 5 is a graph showing the relationship of fresh water injection and saturated brine production volume to producing days and increasing underground cavern dimensions; and

FIGURE 6 is a view of the ultimate development of the dual chamber cavern storing hydrocarbon in the upper chamber and after having produced brine in the lower chamber over an extended period of time.

According to the present invention there is provided an apparatus for and method of making a dual purpose underground storage cavern for storage of water-insoluble fluids and concomitant production of concentrated salt solution from a single bore hole; comprising: drilling a bore hole into a water soluble salt formation to a first depth of about that of the bottom of a first lower cavern to be formed; cementing casing pipe into said bore hole to a higher second depth; circulating fresh water through the first of two conduit means depending within said casing pipe and spaced apart at a first level; removing salt from said formation as solution through the other of said conduit means to form a first cavern; moving said first and second conduit means to a second level within said bore hole and spaced apart thereat; forming a second cavern by circulation of fresh water in a similar manner; moving said first and second conduit means to a third level within said bore hole intermediate said first and second levels and spaced apart thereat; substantially filling the upper cavern with said water insoluble fluid by introducing the same through said casing pipe to displace salt solution through one of said first and second conduit means; storing the thus introduced water insoluble fluid in said upper cavern; removing the stored fluid from said upper cavern as needed through said casing pipe by displacing said stored fluid with the salt solution formed in said lower cavern by the introduction of fresh water through the lower of said first and second conduit means; producing salt solution from said formation by introducing fresh water through the lower of said first and second conduit means; withdrawing the resulting salt solution through the upper of said first and second conduit means, whereby further enlargement of said upper cavern is substantially avoided.

Thus, a dual chamber underground storage cavern is formed, the upper chamber of which is substantially filled with stored fluid, such as LPG, and the lower chamber is filled with insolubles and saturated salt solution, and saturated brine can be produced, as needed, over an extended period of time.

It is, of course, important that the finished underground storage cavern be free from any leaks through which the product subsequently stored therein may be lost. In making caverns in salt formations to be used for the storage of liquefied petroleum gas, extra care is necessary to make certain there are no leaks in the roof of the cavern, when, because of the nature of the strata immediately above the salt, viz., containing harmful fractures, or being soft and crumbly and subject to caving, leaks are possible. The obvious solution to such a problem is to form the cavern completely in the salt formation, maintaining a layer of salt over the cavern thick enough to insure sufficient support, cementing casing pipe directly into the salt.

Referring now to the drawing, wherein like parts have been designated with like reference numerals, and to FIGURE 1 in particular, in which bore hole 11 is drilled into salt formation 12, and casing pipe 13 is cemented into the salt at the second depth. The bore hole is continued deeper into the formation to a first depth of about that of the bottom of a first lower cavern to be formed. Two concentric strings of tubing 14 and 16 are lowered into the bore hole. In starting solution mining of the lower cavern 17, the lower end of outer conduit 14 is set at a third depth approximately level with the initial roof of this lower cavern to be formed. Inner pipe 16 is set in the bore hole at close proximity to the bottom of the bore hole, which is also the bottom of cavern 17 to be formed.

Fresh water is passed down through inner conduit 16 and salt solution returned to the surface via the annulus defined by outer conduit 14. The rate of circulation of water can be controlled by such means as regulating pumps or valves. Alternatively, water passes down through annulus 14 and salt solution up through inner conduit 16.

When the portion of the formation between the initial positions of conduits 14 and 16 has been mined out to form lower cavern 17 of the desired volume, suitable for deposition of any formation insolubles such as anhydrite, encountered during solution mining, a shift of the position of the conduit is undertaken as shown in FIGURE 2. Outer conduit 14 is raised to a fourth depth of about the roof of the upper storage cavern to be formed, or about 50' below the foot of the cemented casing. Inner conduit 16 is raised to the third depth of about the initial roof of lower cavern 17. Additional fresh water is circulated through inner conduit 16 at a high rate to produce dilute salt solution, which is removed via the annulus defined by outer conduit 14 until sufficient salt has been dissolved to enlarge bore hole 18 to a preselected diameter e.g. about 3 to 5 feet. Water circulation can be reversed occasionally. During the entire solution mining phase, any insoluble materials encountered will collapse upon removal of salt formation support and conveniently collect as debris 19 in the bottom of lower cavern 17.

Next, as shown in FIGURE 3, inner conduit 16 is raised to a fifth depth of about that of the bottom of the upper cavern 21. Again, fresh water is circulated to enlarged bore hole 18 through inner conduit 16 and salt removed as solution through outer conduit 14.

When sufficient salt has been removed from that portion of the formation between the positions of conduits 14 and 16 seen in FIGURE 3, to form the upper storage cavern 21 of desired volume, then water circulation is terminated.

In the next view of the development of the combination well, as shown in FIGURE 4, outer pipe 14 is lowered to said fifth depth, of about the bottom of upper cavern 21, and inner pipe 16 is lowered to said third depth of about the initial roof of lower cavern 17. Fresh water is circulated through enlarged bore hole 18 via inner pipe 16 and flows upwardly and out through the annulus via pipe 14, the circulation being at a rate which provides a near-saturated solution at the surface. Brine production is terminated, as desired.

Product LPG, or like hydrocarbon, is stored in upper cavern 21 by pumping hydrocarbon down casing pipe 13, and withdrawing an equivalent volume of brine via pipe 14. Product LPG is removed via casing pipe 13, and displacing fluid is supplied as water via inner pipe 16. Thus brine is provided for product displacement in the upper cavern instead of water, where further enlargement of the upper cavern is to be avoided. Alternatively, a separate supply of brine can be introduced via pipe 14 to displace product withdrawn via casing pipe. A typical case for the development of the dual purpose cavern of this invention, including depths, volumes and flow rates experienced is set forth in the example below.

EXAMPLE

Sizing of the lower cavern, or bell, for storage of insolubles is calculated in the following manner. A 200,000 barrel upper cavern for the storage of LP-gas is to be formed in a salt dome. From corings taken during the drilling, it is estimated that salt contains 10% anhydrite, or other insolubles. 300,000 barrels of salt, based on 2 million barrels of brine produced, will be mined from the bore hole between the lower and upper cavern in the early days of saturated brine production to achieve a configuration as shown in FIGURE 4. Solution mining of these combined volumes should produce about 50,000 barrels of insolubles, thus requiring the lower cavern 17 to be at least an equivalent volume.

A combination well for the underground storage of LP-gas and brine production will be developed between the depths of 1,700' and 3,500'. A storage volume of 200,000 barrels will be developed between 1,700' and 2,100'. Brine will be produced from the unit between the depths of 2,100' and 3,300'.

After the permanent casing has been set and cemented at 1,700' and the well has been drilled to total depth of 3,500', development of the unit will proceed as follows and as illustrated on the attached FIGURE 1.

Stage 1—Development of bell for storage of insolubles

With the protective casing set at 3,300' and the wash casing set at 3,500' develop a storage chamber 17 for the storage of insolubles within the salt by injecting fresh water in the wash casing 16 and removing brine through the annular space between the protective casing 14 and the wash casing. The required size of this chamber is dependent upon the percentage of insolubles in the salt, the volume of the storage chamber to be developed between 1,700' and 2,100', and the volume of brine to be produced during the first operation sequence.

Stage 2—Enlarge drill hole

During the development of the LP-gas storage volume, the anhydrite will drop through the drill hole 11 into the storage chamber below. In order to assure free passage for this material, and in order to assure that re-entry into the hole with the wash casing can be accomplished for Stage 4, the drill hole should be enlarged to approximately 3' to 5' in diameter. A larger diameter may be required if the hole deviation from vertical between the depths of 1,700' and 2,100' averages more than approximately $\frac{1}{4}$ degree. A directional deviation survey run immediately after the drilling of the hole will furnish the required information.

With the protective casing 14 set as approximately 1,750' and the wash casing 16 set at approximately 3,300', wash the drill hole at a high rate to produce dilute brine. The wash rate should be high enough for this stage to produce brine somewhat less than saturated so that salt solution and corresponding hole enlargement will occur at the critical depth 2,100', see FIGURE 2.

Stage 3—Development of storage volume

After the drill hole has been enlarged to the required diameter 18, set the wash casing at approximately 2,100'. Develop the storage section by injecting fresh water through the wash casing 16 and removing brine through the annular space between the protective casing 14 and the wash casing. See FIGURE 3.

Stage 4—Storage of product and production of brine

After the storage section 21 has been washed to the required volume, set the protective casing at 2,100' and the wash casing at 3,300'. The unit is now ready for the storage of LP-gas in the storage section and the production of brine between 2,100' and 3,300'. Fresh water is injected through the wash casing and brine is removed through the annular space between the protective casing and the wash casing. See FIGURE 4. The fresh water

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injection rate should be regulated in order to produce brine which is near saturation; and thereby avoid further enlargement of the upper LP-gas storage cavern. FIGURE 5 shows the maximum injection rates for this system when producing brine of 95% minimum saturation, and the accumulative volume of brine produced during the first 64 days of brine production. The sharply rising maximum water injection rate, predicated on 95% minimum saturation, is a function of the fast increasing surface area of exposed salt in the enlarging cavern. The indicated 900 gallons per minute water injection is the maximum pumping rate assumed based on the available pumping equipment. Otherwise, the maximum water injection rate might be extrapolated indefinitely.

The structure illustrated in FIGURE 6 represents the ultimate development of the unit after 30,000,000 to 40,000,000 barrels of brine have been produced. A shape and volume survey should be run on the unit at intervals of 3,000,000 barrels of brine production, for example. Adjustments in this incremental production between surveys may be required from time to time based on information derived from the shape and volume surveys of the unit.

Reasonable variation and modification are possible within the scope of the foregoing disclosure, the drawing and the appended claims to the invention.

I claim:

1. A method of making a dual purpose underground storage cavern for storage of water-insoluble fluids and production of concentrated salt solution in situ from a single bore hole, comprising:

- (a) drilling a bore hole into a water soluble salt formation to a first depth of about that of the bottom of a first lower cavern to be formed;
- (b) setting a first conduit means in said bore hole to a second depth of about the desired initial roof of said first lower cavern;
- (c) setting a second conduit means in said bore hole at close proximity to said bottom of said first lower cavern;
- (d) circulating fresh water to said bore hole through one of said conduit means and removing salt from said formation as solution thru the other of said conduit means until sufficient salt has been removed from the formation between the outlets of said conduit means to form said first cavern of desired volume for deposition therein of any insolubles encountered in solution mining said formation;
- (e) positioning one of said first and second conduit means at a third depth of about the roof of a second upper storage cavern to be formed;
- (f) positioning the other of said first and second conduit means at a fourth depth that is spaced upwardly from said second depth at a location desired in said bore for the bottom of said second upper storage cavern;
- (g) circulating fresh water to said bore hole thru one of said conduit means and removing salt from said bore hole as solution thru the other of said conduit means until sufficient salt has been removed between said conduit outlets to form said second cavern of desired volume for storage of a water immiscible fluid therein;
- (h) lowering one of said first and second conduit means to about said fourth depth;
- (i) lowering the other of said first and second conduit means to about said second depth;
- (j) introducing water insoluble fluid to be stored into the upper cavern;
- (k) circulating fresh water thru said bore hole thru one of said conduit means and removing means from as needed thru the other of said conduit means as solution at a rate which provides a substantially saturated salt solution; and

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(l) terminating production of substantially saturated salt solution, as desired.

2. A method for storing water-insoluble fluids and producing a concentrated salt solution in situ from a single underground cavern, comprising:

- (a) drilling a bore hole into a water soluble salt formation to a first depth of about that of the bottom of the first lower cavern to be formed;
 - (b) cementing casing pipe into said bore hole to a higher second depth not substantially lower than the initial roof of the desired second upper storage cavern;
 - (c) setting a first conduit means in said bore hole to a third depth of about the desired initial roof of said first lower cavern;
 - (d) setting a second conduit means in said bore hole at close proximity to said bottom of said first lower cavern;
 - (e) circulating fresh water to said bore hole through said second conduit means and removing salt from said formation as solution thru the first of said conduit means until sufficient salt has been removed from the formation between the outlets of said conduit means to form said first cavern of desired volume for deposition therein of any insolubles encountered in solution mining said formation;
 - (f) raising said first conduit means to a fourth depth of about the roof of the second upper storage cavern to be formed;
 - (g) raising said second conduit means to said third depth;
 - (h) circulating fresh water to said bore hole thru said second conduit means and removing salt from said bore hole as solution thru the first of said conduit means until sufficient salt has been removed to enlarge the bore hole to a preselected diameter;
 - (i) raising said second conduit to a fifth depth of about the bottom of said second upper storage cavern;
 - (j) circulating fresh water to said bore hole thru said second conduit means and removing salt from said bore hole as solution thru the first of said conduit means until sufficient salt has been removed between said conduit outlets to form said second cavern of desired volume for storage of a water immiscible fluid therein;
 - (k) lowering said first conduit means to about said fifth depth;
 - (l) lowering said second conduit means to about said third depth;
 - (m) introducing water insoluble fluid to be stored into the upper cavern;
 - (n) circulating fresh water thru said partly enlarged bore hole thru said second conduit means and utilizing the saturated salt solution so formed to remove the stored fluid as needed; and
 - (o) terminating production of saturated salt solution as desired.
3. A method for storing water-insoluble fluids and producing a concentrated salt solution in situ from a single underground cavern comprising:
- (a) drilling a bore hole into a water soluble salt formation to a first depth of about that of the bottom of the first lower cavern to be formed;
 - (b) cementing casing pipe into said bore hole to a higher second depth not substantially lower than the initial roof of the desired second upper storage cavern;
 - (c) setting an outer first conduit means in said bore hole to a third depth of about the desired initial roof of said first lower cavern;
 - (d) setting an inner second conduit means in said bore hole at close proximity to said bottom of said first lower cavern;
 - (e) circulating fresh water to said bore hole through said second conduit means and removing salt from

- said formation as solution thru the first of said conduit means until sufficient salt has been removed from the formation between the outlets of said conduit means to form said first cavern of desired volume for deposition therein of any insolubles encountered in solution mining said formation;
- (f) raising said first conduit means to the fourth depth of about the roof of a second upper storage cavern to be formed;
- (g) raising said second conduit means to said third depth;
- (h) circulating fresh water to said bore hole thru said second conduit means and removing salt from said bore hole as solution thru the first of said conduit means until sufficient salt has been removed to enlarge the bore hole to a preselected diameter;
- (i) raising said second conduit to a fifth depth of about the bottom of said second upper storage cavern;
- (j) circulating fresh water to said bore hole thru said second conduit means and removing salt from said bore hole as solution thru the first of said conduit means until sufficient salt has been removed between said conduit outlets to form said second cavern to desired volume for storage of a water immiscible fluid therein;
- (k) lowering said first conduit means to about said fifth depth;
- (l) lowering said second conduit means to about said third depth;
- (m) introducing water insoluble fluid to be stored into the upper cavern;
- (n) circulating fresh water thru said partly enlarged bore hole thru said second conduit means and removing salt therefrom as needed thru the first of said conduit means as solution at a rate which provides a substantially saturated salt solution; and
- (o) terminating production of substantially saturated salt solution as desired.
4. A method for storing water-insoluble fluids and producing a concentrated salt solution from a single underground cavern, comprising:
- (a) drilling a bore hole into a water soluble salt formation to a first depth of about that of the bottom of a first lower cavern to be formed;
- (b) cementing casing pipe into said bore hole to a higher second depth not substantially lower than the initial roof of the desired second upper storage cavern;
- (c) setting an outer first conduit means in said bore hole to a third depth of about the desired initial roof of said first lower cavern;
- (d) setting an inner second conduit means in said bore hole at close proximity to said bottom of said first lower cavern;
- (e) circulating fresh water to said bore hole through said second conduit means and removing salt from said formation as solution thru the first of said conduit means until sufficient salt has been removed from the formation between the outlets of said conduit means to form said first cavern of desired volume for deposition therein of any insolubles encountered in solution mining said formation;
- (f) raising said first conduit means to a fourth depth of about the roof of the second upper storage cavern to be formed;
- (g) raising said second conduit means to said third depth;
- (h) circulating fresh water to said borehole thru said second conduit means and removing salt from said bore hole as solution thru the first of said conduit means until sufficient salt has been removed to enlarge the bore hole to a preselected diameter;
- (i) raising said second conduit to a fifth depth of about the bottom of second upper storage cavern;

- (j) circulating fresh water to said bore hole thru said second conduit means and removing salt from said bore hole as solution thru the first of said conduit means until sufficient salt has been removed between said conduit outlets to form said second cavern of desired volume for storage of a water immiscible fluid therein;
- (k) lowering said first conduit means to about said fifth depth;
- (l) lowering said second conduit means to about said third depth;
- (m) introducing into the upper cavern through said casing pipe a water insoluble fluid to be stored;
- (n) circulating fresh water thru said partly enlarged bore hole thru said second conduit means and removing salt therefrom as needed thru the first of said conduit means as solution at a rate which provides a substantially saturated salt solution and utilizing the saturated salt solution so formed to remove the stored fluid as needed; and
- (o) terminating production of substantially saturated salt solution as desired.
5. The method according to claim 4 wherein said water-insoluble fluid is liquefied petroleum gas.
6. An improved structure for storing water-insoluble fluids and producing in situ concentrated salt solution comprising, in combination:
- (a) a first lower underground cavern formed by dissolving a portion of the interior of a water soluble salt formation;
- (b) a second upper underground cavern similarly formed and disposed intermediate said lower cavern and the surface of the earth;
- (c) a substantially vertical passage communicating between said upper and lower caverns;
- (d) a cemented substantially vertical casing pipe communicating between said upper cavern and said surface;
- (e) two conduit means depending within said casing pipe, the lower end of one of said conduit means extending to the upper portion of said lower cavern, and the lower end of the other of said conduit means extending to the lower portion of said upper cavern, said one of said conduit means being adapted for linear adjustment within said vertical passage so as to permit unimpeded circulation of water there-through;
- (f) means for admitting water through one of said conduit means and withdrawing salt solution from the other of said conduit means;
- (g) means for admitting and withdrawing said water-insoluble fluid thru the casing; and
- (h) substantially saturated salt solution filling said lower cavern.
7. An improved structure for storing water-insoluble fluids and producing in situ concentrated salt solution comprising, in combination:
- (a) a first lower underground cavern formed by dissolving a portion of the interior of a water soluble salt formation;
- (b) a second upper underground cavern similarly formed and disposed intermediate said lower cavern and the surface of the earth;
- (c) a vertical passage communicating between said upper and lower caverns;
- (d) a passageway communicating between the upper portion of said upper cavern and said surface;
- (e) inner and outer conduit means depending within said passageway, the lower end of said outer conduit means extending to the lower portion of said upper cavern, and the lower end of said inner conduit means extending to the upper portion of said lower cavern, said inner conduit means being adapted for linear adjustment within said vertical passage so as to permit unimpeded circulation of water there-

- through at a rate that produces a saturated salt solution;
- (f) means for admitting water through one of said conduit means and withdrawing salt solution from the other of the two conduit means; 5
- (g) means for admitting and withdrawing said water-insoluble fluid thru the passageway to be stored in said upper cavern; and
- (h) substantially saturated salt solution substantially filling said lower cavern. 10
8. A method for storing water insoluble fluids in an underground storage cavern and concomitantly producing in situ concentrated salt solutions therefrom, comprising:
- (a) drilling a bore hole into a water soluble salt formation to a first depth of about that of the bottom of a first lower cavern to be formed; 15
- (b) cementing casing pipe into said bore hole to a higher second depth;
- (c) circulating fresh water through the first of two conduit means depending within said casing pipe and spaced substantially vertically apart at a first level; 20
- (d) removing salt from said formation as solution through the other of said conduit means to form a first cavern;
- (e) moving said first and second conduit means to a second level within said bore hole and spaced substantially vertically apart thereat; 25
- (f) forming a second cavern substantially vertically spaced apart in the bore from said first cavern by circulation of fresh water in a similar manner; 30
- (g) moving said first and second conduit means to a third level within said bore hole intermediate said

- first and second levels and spaced substantially vertically apart thereat;
- (h) substantially filling the upper cavern with said water insoluble fluid by introducing the same through said casing pipe to displace salt solution through one of said first and second conduit means;
- (i) storing the thus introduced water insoluble fluid in said upper cavern;
- (j) removing the stored fluid from said upper cavern as needed through said casing pipe by displacing said stored fluid with the salt solution formed in said lower cavern by the introduction of fresh water through the lower of said first and second conduit means;
- (k) producing salt solution from said formation by introducing fresh water through the lower of said first and second conduit means;
- (l) withdrawing the resulting salt solution through the upper of said first and second conduit means, whereby further enlargement of said upper cavern is substantially avoided.

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EARL J. WITMER, *Primary Examiner.*

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,277,654

October 11, 1966

Amos J. Shiver

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 5, lines 72 and 73, strike out "means from" and insert instead -- salt therefrom --.

Signed and sealed this 22nd day of August 1967.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

EDWARD J. BRENNER

Commissioner of Patents