Aug. 1, 1961 P. G. CARPENTER 2,994,200

MAKING UNDERGROUND STORAGE CAVERNS

Original Filed June 16, 1952

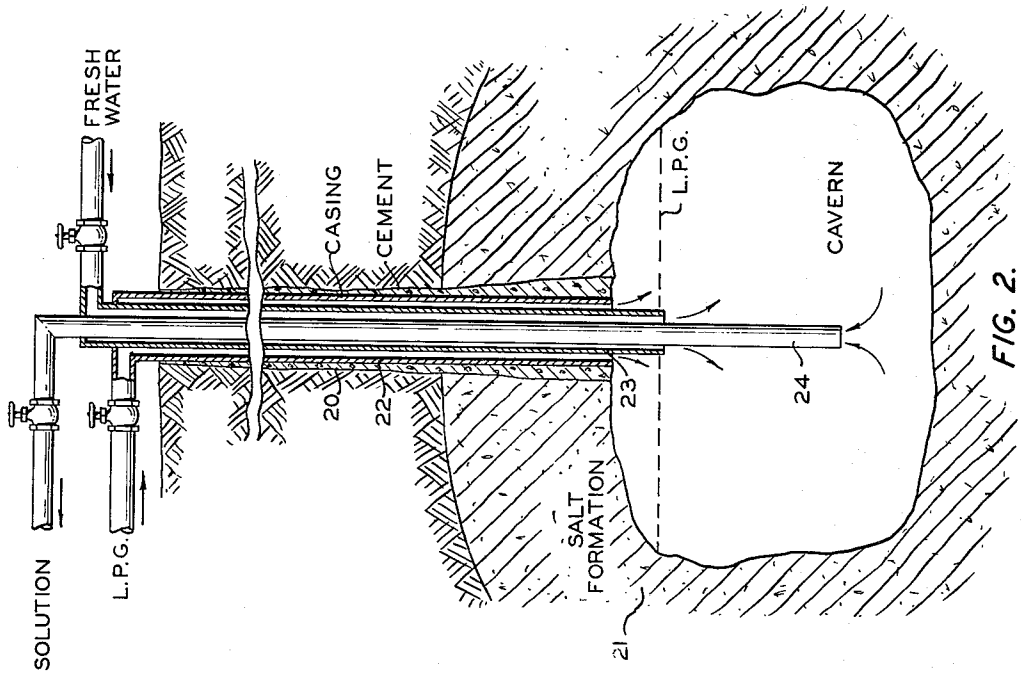


FIG. 2.

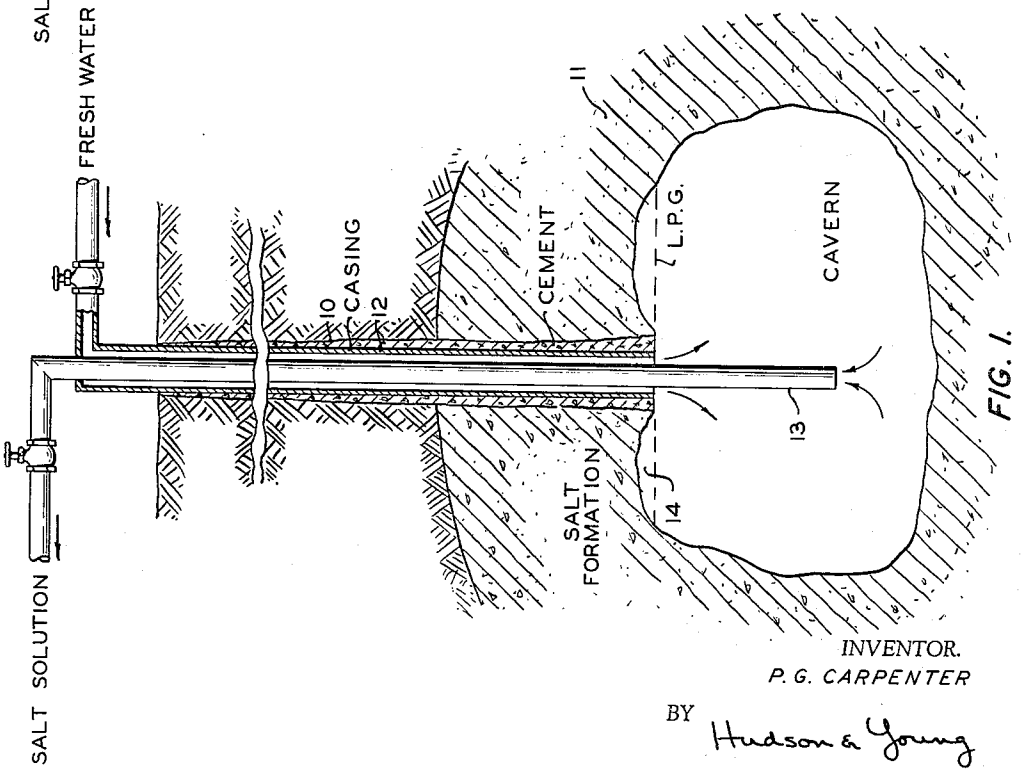


FIG. 1.

INVENTOR.
P. G. CARPENTER

BY Hudson & Young

ATTORNEYS

United States Patent Office 2,994,200 Patented Aug. 1, 1961

2,994,200

MAKING UNDERGROUND STORAGE CAVERNS

Paul G. Carpenter, Baton Rouge, La., assignor to Phillips Petroleum Company, a corporation of Delaware

Continuation of application Ser. No. 293,868, June 16, 1952. This application Jan. 28, 1957, Ser. No. 636,811
18 Claims. (Cl. 61—5)

This invention relates to an improved method for making underground storage caverns. In one of its aspects this invention relates to a method for protecting the roof of an underground storage cavern in a salt formation while forming the cavern by dissolving out the salt with water.

This application is a continuation of my application Serial No. 293,868, filed June 16, 1952.

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 these days of allocation of critical 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 much as six times less than 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.

So far as is known no attempts have been made to apply the principles herein involved to formations other than salt. However, many shales readily disintegrate in water and such formation may be employed. Also, in some cases it may be feasible to dissolve space out of massive limestone with hydrochloric acid. The extensive occurrence of salt deposits believed suitable to this method of storage is another factor in favor of its increasing use.

In the usual case there is a layer of hard anhydrite above the salt formation and when drilling the well casting pipe is cemented in this hard anhydrite layer. The bore hole is then extended into the salt formation and fresh water is circulated down through the tubing to dissolve out part of the salt thus forming a cavern. In those cases the hard anhydrite layer forms the roof of the resulting cavern and the problem of caving of the roof or dissolving out the foot of the casing is not encountered. In many instances, however, where there is no hard anhydrite layer, such as in a salt dome, or in other instances where the formation above the salt formation is subject to caving, casing pipe is cemented directly into the salt bed to a length which will result in a salt layer above the cavern roof of sufficient thickness which will not cave. In this instance it is necessary to protect the foot of the casing and the roof of the resulting cavern from the dissolving action of the solvent employed. One cause of eating the roof is the fact that salt water is heavier than fresh water. Thus the fresh water will tend to rise to the top of the cavern and thus dissolves the roof away faster than the bottom or walls of the cavern. It is to the solution of this problem and the prevention of contamination of liquefied petroleum products subsequently stored in the resulting caverns that the present invention is directed.

An object of this invention is to provide an improved method of making an underground storage cavern.

It is another object of this invention to provide a method for protecting the roof of an underground storage cavern in a salt formation while forming the cavern by dissolving out the salt with water, and preventing unnecessary contamination of the material subsequently stored in the cavern.

Further and additional objects of this invention will be apparent from the accompanying descriptions and drawing.

FIGURE 1 of the drawing is a vertical cross-sectional view partly in elevation showing one embodiment of my invention.

FIGURE 2 of the drawing is a similar view showing another embodiment of my invention.

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 is 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. However, the problem then arises of protecting the roof of the cavern around the foot of the bore hole from the dissolving action of the solvent employed, to prevent leaks from developing around the cemented casing pipe into a faulty upper formation and caving of the remainder of the cavern roof. It has been suggested in the art of mining salt by dissolving it from an underground formation with water, to protect the roof of the resulting cavern around the foot of the bore hole by maintaining (1) a layer of compressed air, or (2) a non-solvent such as petroleum or shale oil between the roof of the cavern and the solvent. However, when, according to the latter method, diesel oil was employed in forming a salt cavern for storing liquefied petroleum gas the LPG subsequently stored therein was contaminated and required a reprocessing before it could be used. If the former method is employed it is necessary for best results to use two strings of pipe besides the casing pipe and employ extremely high air pressure to protect the roof of the cavern. I have now discovered that the problems hereinbefore described can be concomitantly and economically solved by maintaining as a separate phase liquefied petroleum gas between the roof of the cavern and the solvent employed.

Referring now to FIGURE 1 of the drawing, one embodiment of my invention employing a single string of pipe is illustrated. Bore hole **10** is drilled into salt formation **11** to a depth dependent upon the desired thickness of salt to be maintained between the cavern and the adjacent upper strata. Of course, in those instances where the strata immediately above the salt layer in which the cavern is to be formed is a hard impervious substance suitable to form the roof of the cavern, such as hard anhydrite, the method of this invention is unnecessary. Casing pipe **12** is set into the salt formation and cemented therein to give it a firm footing. The bore hole can then be deepened to any desired depth into the salt formation. Fresh water is then piped down to the salt formation via pipe **13** and returned to the surface through the casing pipe. This circulation is the opposite of that shown in the drawing but is the preferred way of starting the cavern and particularly to dissolve some salt from around the foot of the casing pipe causing said foot to project from the roof of the cavern. This can be described as a recess **14** in the cavern roof adjacent to the foot of the casing pipe. The depth of this recess or depression is dependent

upon such factors as the thickness of the salt to the upper strata, the ultimate size of the cavern, and length of cementing of casing pipe. Three to ten feet could be set as an optimum depth. However, since it would be difficult to determine the extent of the recess, it can be reasonably assumed that after the cavern has reached a capacity of around 500 barrels, formed as hereinbefore described, that a recess of the desired size will exist. At this stage in the formation of the cavern the circulation of fresh water is stopped and liquefied petroleum gas is spotted in the recess in the cavern roof, thus forming a protective layer between the roof of the cavern and the fresh water solvent. This spotting operation can be accomplished either by passing the LPG down casing pipe **12**, or down pipe **13**. In the latter instance in order to get better spotting, it is desirable to raise pipe **13** so that its lower end is approximately level with the foot of the casing pipe, and then pass LPG down to the cavern. The LPG is generally passed down as a liquid; however, it can be pumped down as a gas under pressure such that it will be a liquid upon reaching the cavern. After the LPG is spotted it is preferred that the circulation be reversed; that is, as shown in FIGURE 1, passing fresh water down the casing pipe and returning the resulting salt solution to the surface via pipe **13**. This reverse circulation is best suited to maintain the less dense LPG as a separate phase on top of the water solvent and between the cavern roof. However, the circulation can be varied occasionally to facilitate better dissolving action by the water. The rate of circulation of water can be controlled in conventional ways, such as by regulating pumps or valves. The amount of LPG initially spotted will depend on the size of the cavern. In some instances it may be necessary to add LPG as the size of the cavern increases, or because some has been lost in the course of water circulation. Because of the depth of the cavern, viz., 250 to 3000 feet generally, and because the LPG will be trapped in recess **14** under pressure, no appreciable amount will be lost due to evaporation.

Referring to FIG. 2 of the drawing, this embodiment of my invention employs two concentric strings of pipe within the casing pipe. Bore hole **20** is drilled into salt formation **21** and casing **22** cemented therein. The hole is then continued deeper into the formation and two concentric strings of pipe **23** and **24** are lowered to the salt formation. In starting the cavern the lower end of outer pipe **23** is approximately level with the foot of casing pipe **22** and the lower end of inner pipe **24** extends farther into the hole. Fresh water is passed down through outer pipe **23** and salt solution returned to the surface via inner pipe **24**. The rate of circulation of water can be controlled by such means as regulating pumps or valves. As the cavern enlarges outer pipe **23** is lowered and at the same time sufficient LPG is passed down to the cavern through casing pipe **22** to form a layer on top of the water and thus protect the roof of the cavern from the dissolving action of the water. By operating in this manner the roof of the resulting cavern has a slope which increases its resistance to caving. The circulation can be reversed occasionally. There may or may not be a recess formed in the cavern roof adjacent to the foot of casing pipe **22** as hereinbefore described, depending upon how soon after circulation is started that outer pipe **23** is lowered and LPG passed down. When using two strings of pipe there is no need to trap the LPG in the roof of the cavern since it can be readily maintained there via the casing pipe. The method of the present invention when employing two strings of pipe for circulating water is a definite improvement over the use of compressed air in that the probability that the water will attack the roof of the cavern is much less and further, it is possible to store LPG while actually forming the cavern.

While this invention has been described in terms of its preferred embodiments those skilled in the art will readily appreciate that modifications can be made without departing from the spirit and scope of the invention.

I claim:

1. A method of making an underground storage cavern for liquefied petroleum gas, comprising the steps of circulating through an underground formation a liquid which is a solvent for said formation to form a recess in the roof of said formation, spotting liquefied petroleum gas in said recess, continuing the circulation of said solvent liquid whereby an underground cavern is leached out of said formation, and shielding the roof of said cavern from said solvent during the leaching step by maintaining a layer of liquefied petroleum gas between the surface of said solvent and said cavern roof.

2. A method of making an underground storage cavern for liquefied petroleum gas, comprising drilling into a water soluble salt formation, cementing casing pipe into said formation, circulating fresh water to said formation through one conduit means, removing salt from said formation as solution through another conduit means until sufficient salt has been dissolved from around the cemented casing foot in the cavern roof to form a recess in said roof around said foot, spotting liquefied petroleum gas in said recess, and maintaining liquefied petroleum gas during the enlargement of said cavern as a separate phase between the cavern roof and the water solvent whereby said cavern roof is protected from further dissolution and contamination of liquefied petroleum gas subsequently stored in said cavern is prevented.

3. A method of making an underground storage cavern for liquefied petroleum gas comprising drilling into a water soluble salt formation, cementing casing pipe into said formation, circulating fresh water to said formation through an inner string of pipe, removing salt from said formation as solution through the casing pipe until sufficient salt has been dissolved from around the cemented casing foot in the cavern roof to form a recess in said roof around said foot, spotting liquefied petroleum gas in said recess, reversing the circulation and then while enlarging by circulating more water maintaining said liquefied petroleum gas as a separate phase between the roof of the cavern and the water solvent whereby the roof of the cavern is protected from further dissolution and contamination of liquefied petroleum gas subsequently stored in said cavern is prevented.

4. The method according to claim 3 where in said recess is from three to ten feet in depth.

5. A method of making an underground storage cavern for liquefied petroleum gas by drilling into a water soluble salt formation, cementing casing into said formation, positioning first and second strings of pipe within said casing so that the lower end of said first string of pipe is approximately level with the foot of said casing and the lower end of said second string of pipe is lower than the foot of said casing, circulating fresh water through one of said strings of pipe, removing salt from said formation in solution through the other of said pipes, gradually lowering said first pipe string from the foot of the casing as formation of said cavern proceeds, passing liquefied petroleum gas down to said cavern and then while enlarging by circulating more water maintaining said liquefied petroleum gas as a separate phase between the cavern roof and the water solvent whereby said cavern roof is protected from the dissolving action of solvent and contamination of liquefied petroleum gas subsequently stored in said cavern is prevented.

6. A method for storing liquefied petroleum gas in an underground storage cavern, comprising the steps of circulating through an underground formation a liquid which is a solvent for said formation whereby an underground cavern is leached out of said formation, shielding the roof of said cavern from said solvent during the leaching operation by maintaining a layer of liquefied petroleum gas between the surface of said solvent and said cavern roof,

and filling said cavern at the conclusion of the leaching operation with liquefied petroleum gas.

7. A method for storing liquefied petroleum gas in an underground storage cavern, comprising circulating an aqueous liquid from the surface of the earth through a water soluble underground formation and back to the surface to dissolve out a cavern in said formation, maintaining a layer of liquefied petroleum gas between the cavern roof and the surface of said solvent during preparation of said cavern, whereby said cavern roof is protected from dissolution, and filling said cavern at the conclusion of the leaching operation with liquefied petroleum gas which is maintained in air-tight storage therein.

8. A method for storing liquefied petroleum gas in an underground storage cavern, comprising drilling to a suitable underground formation, cementing casing pipe into said formation, passing a liquid to said formation and forming a cavern therein by the action of said liquid on said formation and removing part of said formation admixed with said liquid, concomitantly protecting the cavern roof from the action of said liquid and preventing contamination of liquefied petroleum gas subsequently stored in said cavern by maintaining said liquefied petroleum gas as a separate phase between said cavern roof and said liquid, and filling said cavern at the conclusion of the leaching operation with liquefied petroleum gas which is maintained in airtight storage therein.

9. A method for storing liquefied petroleum gas in an underground storage cavern, comprising drilling into a water soluble salt formation, cementing casing pipe into said formation, circulating fresh water to said formation through one conduit means, removing salt from said formation as solution through another conduit means until sufficient salt has been dissolved, maintaining liquefied petroleum gas during the enlargement of said cavern as a separate phase between the cavern roof and the water solvent whereby said cavern roof is protected from further dissolution and contamination of liquefied petroleum gas subsequently stored in said cavern is prevented, and filling said cavern at the conclusion of the leaching operation with liquefied petroleum gas which is maintained in air-tight storage therein.

10. A method for storing liquefied petroleum gas in an underground storage cavern, comprising drilling into a water soluble salt formation, cementing casing pipe into said formation, circulating fresh water to said formation through one conduit means, removing the salt from said formation as solution through another conduit means until sufficient salt has been dissolved from around the cemented casing foot in the cavern roof to form a recess in said roof around said foot, spotting liquefied petroleum gas in said recess, maintaining liquefied petroleum gas during the enlargement of said cavern as a separate phase between the cavern roof and the water solvent whereby said cavern roof is protected from further dissolution and contamination of liquefied petroleum gas subsequently stored in said cavern is prevented, and filling said cavern at the conclusion of the leaching operation with liquefied petroleum gas which is maintained in air-tight storage therein.

11. A method for storing liquefied petroleum gas in an underground storage cavern without contaminating said gas with other hydrocarbon material, comprising the steps of drilling into a water soluble salt formation, cementing casing pipe into said formation, circulating fresh water to said formation through an inner string of pipe, removing salt from said formation as solution through said casing pipe until sufficient salt has been dissolved from around the cemented casing foot in the cavern roof to form a recess in said roof around said foot, spotting liquefied petroleum gas in said recess, reversing the circulation and then while enlarging said cavern by circulating more fresh water maintaining said liquefied petroleum gas as a separate phase between the roof of said cavern and the water solvent whereby the

roof of the cavern is protected from further dissolution, substantially filling the cavern with liquefied petroleum gas by introducing the same through said casing pipe into said cavern to displace said salt solution through said inner string of pipe, storing the thus introduced liquefied petroleum gas in said cavern, and removing the stored liquefied petroleum gas from said cavern as needed through said casing pipe by displacing said stored liquefied petroleum gas with said salt solution introduced in said cavern through said inner string of pipe.

12. A method for storing liquefied petroleum gas in an underground storage cavern without contaminating said gas with other hydrocarbon material, comprising the steps of drilling into a water soluble salt formation, cementing the casing pipe into said formation, circulating fresh water through the first of two strings of pipe within said casing pipe, removing salt from said formation in solution through the other of said pipes, the base of the said first pipe being near the bottom of the resulting cavern and the base of the other pipe being gradually lowered from the foot of the casing pipe as the formation of the cavern proceeds, passing sufficient liquefied petroleum gas down to said cavern through said casing pipe while said other pipe is being gradually lowered whereby the liquefied petroleum gas forms a separate phase between the roof of the cavern and the water solvent, continuing the formation of the cavern by dissolving said salt with said fresh water, substantially filling the cavern with liquefied petroleum gas by introducing the same through said casing pipe into said cavern to displace said salt solution through said first string of pipe, storing the thus introduced liquefied pertoleum gas in said cavern, and removing the stored liquefied petroleum gas from said cavern as needed through said casing pipe by displacing said stored liquefied petroleum gas in said cavern, and removing the stored said cavern through said first string of pipe.

13. A method for storing liquefied petroleum gas in an underground storage cavern without contaminating said gas with other hydrocarbon material, comprising the steps of drilling into a water soluble salt formation, cementing the casing pipe into said formation, circulating fresh water through the first of two strings of pipe within said casing pipe, removing salt from said formation in solution through the other of said pipes, the base of the said first pipe being near the bottom of the resulting cavern and the base of the other pipe being gradually lowered from the foot of the casing pipe as the formation of the cavern proceeds, occasionally reversing the circulation of said fresh water and said salt solution, passing sufficient liquefied petroleum gas down to said cavern through said casing pipe while said other pipe is being gradually lowered whereby the liquefied petroleum gas forms a separate phase between the roof of the cavern and the water solvent, continuing the formation of the cavern by dissolving said salt with said fresh water, substantially filling the cavern with liquefied petroleum gas by introducing the same through said casing pipe into said cavern to displace said salt solution through said first string of pipe, storing the thus introduced liquefied petroleum gas in said cavern, and removing the stored liquefied petroleum gas from said cavern as needed through said casing pipe by displacing said stored liquefied petroleum gas with said salt solution introduced in said cavern through said first string of pipe.

14. A method for storing liquefied petroleum gas in an underground storage cavern without contaminating said gas with other hydrocarbon material, comprising the steps of drilling into a water soluble salt formation, cementing the casing pipe into said formation, circulating fresh water through the outer of two concentric strings of pipe within said casing pipe, removing salt from said formation in solution through the inner of said pipes, the base of the inner pipe being near the bottom of the resulting cavern and the base of the outer pipe being gradually lowered from the foot of the casing pipe as the forma-

tion of the cavern proceeds, occasionally reversing the circulation of said fresh water and said salt solution, passing sufficient liquefied petroleum gas down to said cavern through said casing pipe while said outer pipe is being gradually lowered whereby the liquefied petroleum gas forms a separate phase between the roof of the cavern and the water solvent, continuing the formation of the cavern by dissolving said salt with said fresh water, substantially filling the cavern with liquefied petroleum gas by introducing the same through said casing pipe into said cavern to displace said salt solution through said inner string of pipe, storing the thus introduced liquefied petroleum gas in said cavern, and removing the stored liquefied petroleum gas from said cavern as needed through said casing pipe by displacing said stored liquefied petroleum gas with said salt solution introduced in said cavern through said inner string of pipe.

15. A method for storing liquefied petroleum gas in an underground storage cavern without contaminating said gas with other hydrocarbon material, comprising the steps of drilling into a water soluble salt formation, cementing the casing pipe into said formation, circulating fresh water through the inner of two concentric strings of pipe within said casing pipe, removing salt from said formation in solution through the outer of said pipes, the base of the inner pipe being near the bottom of the resulting cavern and the base of the outer pipe being gradually lowered from the foot of the casing pipe as the formation of the cavern proceeds, occasionally reversing the circulation of said fresh water and said salt solution, passing sufficient liquefied petroleum gas down to said cavern through said casing pipe while said inner pipe is being gradually lowered whereby the liquefied petroleum gas forms a separate phase between the roof of the cavern and the water solvent, continuing the formation of the cavern by dissolving said salt with said fresh water, substantially filling the cavern with liquefied petroleum gas by introducing the same through said casing pipe into said cavern to displace said salt solution through said outer string of pipe, storing the thus introduced liquefied petroleum gas in said cavern, and removing the stored liquefied petroleum gas from said cavern as needed through said casing pipe by displacing said stored liquefied petroleum gas with said salt solution introduced in said cavern through said outer string of pipe.

16. An improved structure for the storage of liquid petroleum gas comprising, in combination, a sealed underground cavern formed entirely within a water soluble earth formation, a first vertical conduit connecting said cavern with the surface of the earth, the lower end of said first conduit extending to a point near the base of said cavern, a second conduit extending into said cavern but terminating at its lower end portion at a point adjacent the roof of said cavern at which point said roof defines a recess, means for admitting and withdrawing fluids to and from said conduits at the upper ends thereof, an aqueous solution occupying the lower portion of said cavern, and a layer of liquid petroleum gas occupying the space between said aqueous solution and said roof, including said recess, whereby said roof is protected from the solvent action of said aqueous solution.

17. A structure for the storage of liquid petroleum gas comprising in combination, a sealed underground cavern formed entirely within a water soluble earth formation, a first vertical conduit connecting said cavern with the surface of the earth, the lower end of said conduit extending to a point near the base of the cavern, a second conduit annularly spacedly surrounding the first conduit but terminating at its lower end portion at a point adjacent the roof of the cavern, a recess in the cavern roof, said lower end portion of the second conduit opening into said recess and extending below the upper surface thereof, a fluid tight seal between the recess and said second conduit, means for admitting and withdrawing fluids to and from said conduits at the upper ends thereof, an aqueous solution occuping the lower portion of the cavern and a layer of a liquid lighter than and immiscible with the aqueous solution and inert to the earth formation occupying the recess and the space between the aqueous solution and cavern roof whereby the cavern roof is protected from the solvent action of the aqueous solution.

18. A structure for the storage of liquid petroleum gas according to claim 17 wherein said liquid lighter than and immiscible with the aqueous solution is liquid petroleum gas.

References Cited in the file of this patent

UNITED STATES PATENTS

Re. 24,318	Pattinson	May 14, 1957
1,923,896	Trump	Aug. 22, 1933
2,009,535	Trump	July 30, 1935

FOREIGN PATENTS

182,042	Germany	Mar. 7, 1907

OTHER REFERENCES

The Oil and Gas Journal of Aug. 17, 1950, pp. 59 and 60.