

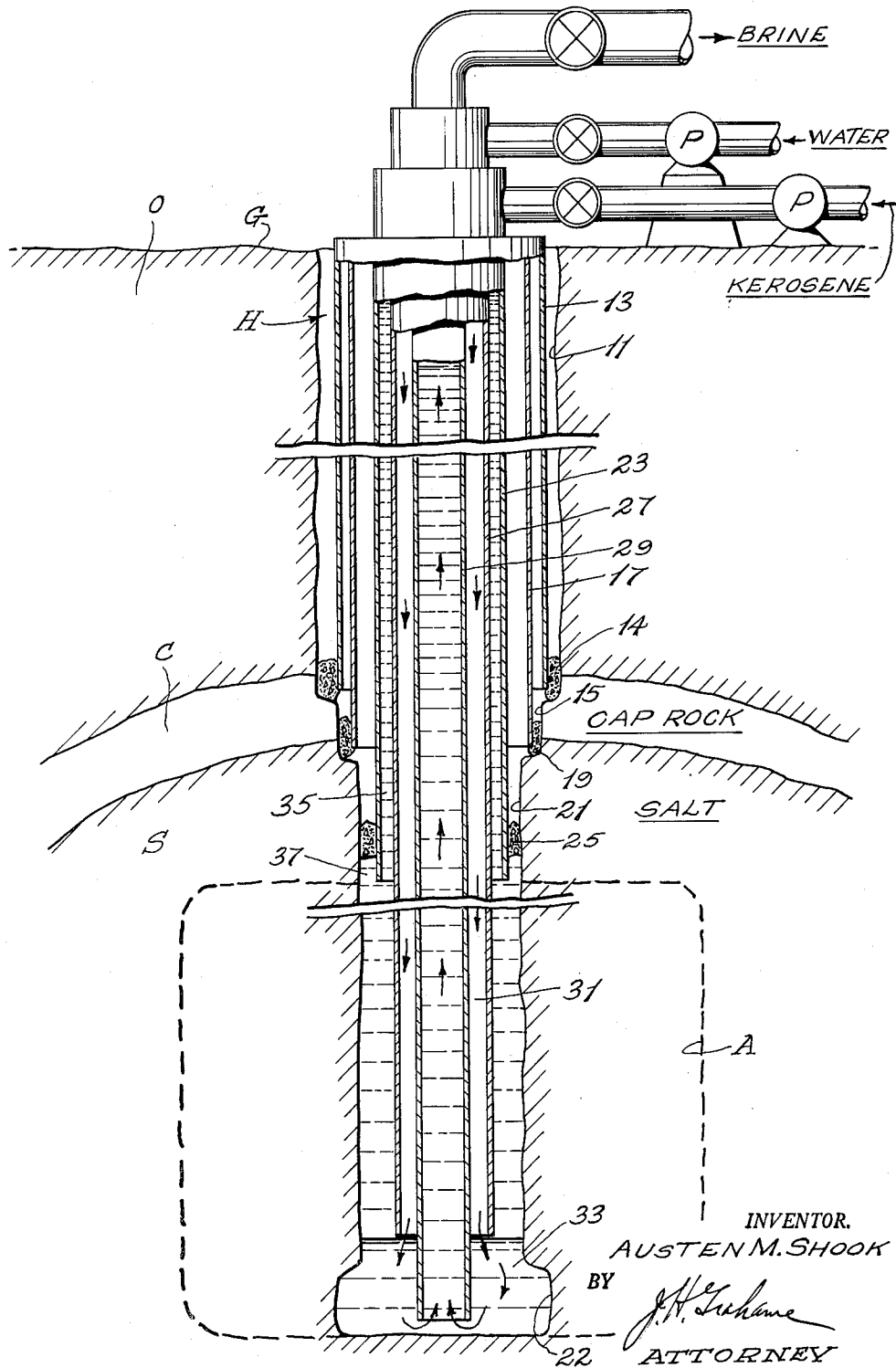
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A. M. SHOOK

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UNDERGROUND STORAGE

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Austen M. Shook, Houston, Tex., assignor to
Texaco Inc., a corporation of Delaware

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This invention relates to a novel method of forming a large storage cavity in an underground formation of a material which is removable by a carrier liquid; and more particularly concerns forming such a cavity in an underground salt formation by circulating water there-through. Another aspect of the invention involves novel apparatus for forming an underground storage cavity.

Such liquefied petroleum gases as butane, propane, and the like, can be stored in the liquefied condition in huge cavities formed in underground salt formations located hundreds of feet below the surface of the ground. A storage cavity is formed by circulating water within the salt formation to dissolve salt, and withdrawing the resultant brine. When the cavity is to be used for the storage of liquefied petroleum gases or the like, it is essential that a tight seal be maintained against the leakage of gas from the cavity. Another problem is the tendency of the various earth strata to cave in as the approach-well is drilled through the overburden.

In the following description the principles of the invention will be set forth by way of illustration only as applied to the production of a cavity in a salt formation by water leaching. It is to be understood that these principles can also be applied to the production of cavities in other types of formations from which material can be removed by water or other carrier liquids, whether by solution or otherwise.

In accordance with the present invention there is provided a novel method for producing an underground storage cavity which is tightly sealed against the loss of gas. This is accomplished in one exemplary embodiment of the invention by drilling a hole down from ground level a substantial distance into a formation of salt such as a salt dome, inserting a first conduit into the hole to a position in the salt dome spaced a substantial distance above the bottom thereof, and forming a fluid-tight seal between this first conduit and the salt wall of the hole.

Then a second conduit for a water supply is inserted through the first conduit in spaced relation thereto to a position below the seal and water is introduced into the salt formation to dissolve salt and form a pool of brine.

After the pool of brine reaches the bottom of the second conduit and before it reaches the vicinity of the seal, there is introduced into the space between the second conduit and the wall of the hole a second liquid which is lighter than and immiscible with the water or other carrier liquid, and which is substantially inert to the salt or other material of the formation, for example, a hydrocarbon fluid such as kerosene. This second liquid then floats on the pool of brine and protects the area of the salt formation adjacent to the seal from attack by water, thus assuring preservation of the seal. Thereafter, brine is removed continuously from the hole in any desired way at about the same rate as fresh water is supplied.

In order to prevent caving of overburden during the drilling of the hole, it should be drilled in several stages, with retaining casings placed as needed.

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The single figure of the drawing shows somewhat schematically a vertical sectional view of apparatus for performing the method of the invention, positioned in the earth to form an underground storage cavity.

Referring to the drawing, a deep hole H is drilled from the surface of the ground G down through intervening formations such as a heterogeneous overburden O and cap rock C deep into the underground salt formation S. Hole H is formed by first drilling a top section 11 of large diameter through the overburden O a short distance into the cap rock C, then setting a casing 13 (e.g., sixteen inches in diameter) into place and cementing it to the cap rock at 14. An intermediate section 15 of intermediate diameter is then drilled from the bottom of top section 11 down through the cap rock and into the salt formation S, and a second casing 17 of intermediate diameter (e.g., 13 $\frac{3}{4}$ inches) is set into place and cemented to both the cap rock and the salt dome as shown at 19. Seal 19 acts as a secondary seal against leakage when the cavity is later used for storage.

The next step is to drill the main section 21 of the hole, of least diameter (e.g., 10–11 inches), from the bottom of 15 deep into the salt dome S where the storage cavity A is to be formed. During the drilling of this main section 21 of the hole, caving of the overburden and cap rock is prevented by the casings 13 and 17. First the top portion of the main section 21 of hole H, for example, the top 250 feet, is drilled, a first conduit 23 (e.g., 9 $\frac{1}{2}$ inches in diameter) is inserted and a fluid-tight seal 25 is formed between it and the wall of the hole H wholly within the salt dome S. Seal 25 can be formed from any suitable conventional material such as Portland cement, and should be located several feet above the bottom of the first conduit 23. Thereafter the rest of the hole is drilled, say 750 feet further into the salt. This can be done in any suitable way, as by drilling a hole of small diameter followed by reaming it to the full final diameter. During the last drilling operation it is advantageous to lubricate the tools with concentrated brine to minimize water attack on the salt in the area of seal 25. In order to assure a high solution rate when water is later admitted to the hole, the bottom portion may be reamed to a larger diameter such as 16 inches for the last few feet as at 22.

A second conduit 27 (e.g., 7 $\frac{1}{2}$ inches in diameter) is then passed through the first conduit 23 in spaced relation thereto to a position below the seal 25 and spaced a short distance, such as 50 feet, above the bottom of the hole H, for supplying water to the salt.

Then a third conduit 29 (e.g., 4 $\frac{1}{2}$ inches in diameter) for the removal of brine is passed through the second conduit 27 to a position a few inches from the bottom of the hole H to receive brine from the cavity. In a typical example the distance from ground surface G to the top of salt dome S was about 750 feet, the first conduit 23 was set about 250 feet into the salt, and the hole H extended about 1,000 feet into the salt.

The washing of salt from the formation S is begun by pumping fresh water down the annulus 31 between the second and third conduits 27 and 29 to flow into contact with the salt walls and dissolve salt therefrom, forming a pool 33 of brine. After the pool 33 reaches the bottom of the second conduit 27 and before it reaches the vicinity of the seal 25, a column of a hydrocarbon liquid such as kerosene is introduced into and maintained in the annulus 35 between the first and second conduits 23 and 27 to float on the pool 33 and protect the salt in the vicinity of the seal 25 from attack by water, thus preserving the seal.

Thereafter brine from pool 33 is continually forced up through the center conduit 29 by the pressure on the column of fresh water in annulus 31. As brine is re-

moved, fresh water flows out the lower end of conduit 27 laterally across the denser brine pool 33 and attacks the salt to form more brine, thus expanding the diameter of the hole H to form the storage cavity A.

When the desired cavity diameter has been reached near the bottom of hole H, the kerosene 35 is removed, the fittings at the top of the well are removed, and the second conduit 27 is raised (e.g., 50 feet) so that fresh water can then attack new portions of the salt formation. Then the fittings are replaced and kerosene again introduced. This operation of shifting the conduit 27 lengthwise is repeated as often as necessary to control the shape of the cavity. Even when the kerosene has been removed the salt adjacent to seal 25 is still protected from attack by water because kerosene is retained in the annulus 37 below seal 25 and between the first conduit 23 and the wall of the hole.

As the formation of the storage cavity A proceeds, a quantity of insoluble detritus such as gypsum sometimes accumulates on the bottom of the hole H and may interfere with the passage of brine into the center conduit 29. This accumulation is most apt to be found after the washing operation has been shut down for several days. Either of two ways can be employed to avoid this difficulty. One satisfactory procedure is to raise the center conduit 29 so that its lower end is always above the accumulated detritus. The other procedure is to lower the center conduit 29 a short distance into the accumulated detritus to receive a slug, and then raise it out of the detritus so that brine will wash the slug up to the surface, this operation being repeated at the will of the operator as often as necessary.

It is obvious that salt can also be removed by circulating fresh water down the central conduit 29, and brine up the annulus 31, although this is less desirable than the above described procedure because fresh water will by-pass without dissolving sufficient salt, and detritus will accumulate in the bottom of the well.

When the portion of hole H in the salt formation S has been expanded to the proper diameter over the desired length, the resulting storage cavity A is then made ready to receive liquefied petroleum gas by removing the kerosene from the annulus 35 and then withdrawing second conduit 27. The kerosene can be removed in any desired way as by relaxing the pressure thereon and allowing the brine to rise through the annulus 35, driving the kerosene before it. A small quantity of kerosene, of course, remains in annulus 37 to protect seal 25, although there is no longer much danger of losing the seal because the pool of brine is saturated and has not much dissolving power.

The storage cavity A is then charged with liquefied petroleum gas by pumping it down through the annular space between first and third conduits 23 and 29 to displace brine from pool 33 up through the third conduit 29 to the surface of the ground where it can be stored in a suitable reservoir. Seal 25 prevents leakage, and its preservation is assured by the presence of liquefied petroleum gas in annulus 37 even when the storage cavity has been emptied of gas. When gas is to be withdrawn

from storage this is accomplished by pumping brine back down into the storage cavity A through the third conduit 29 and driving the gas up through the first conduit 23.

Obviously many modifications and variations of the invention, as hereinbefore set forth, may be made without departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. A method of forming a storage cavity in an underground formation of a material which is removable by a carrier liquid, said method comprising drilling a hole down from ground level a substantial distance into said formation; inserting a first conduit into said hole to a position spaced a substantial distance above the bottom thereof; forming a fluid-tight seal between said first conduit and the wall of said hole wholly within said formation and at a point spaced above the lower end of said first conduit; inserting a second conduit through said first conduit in annularly spaced relation thereto and extending from said ground level to a position below said seal; introducing carrier liquid through a passage within said second conduit into the part of said hole within said formation to remove material therefrom and form a pool of material-laden liquid; before said pool reaches the vicinity of said seal, introducing into and maintaining in the space between said second conduit and said first conduit and also in the space below said seal between said first conduit and the wall of said hole a second liquid which is lighter than and immiscible with said carrier liquid to float on the surface thereof, and which is inert to the material of said formation to protect from attack by said carrier liquid that part of said formation adjacent said seal; and removing material-laden carrier liquid from said hole.

2. A method in accordance with claim 1 wherein the step of removing material-laden carrier liquid is accomplished by maintaining a third conduit within said second conduit in spaced relation thereto with the lower end thereof at a position near the bottom of said hole and below the bottom of said conduit, and said material-laden carrier liquid is removed through said third conduit, and wherein carrier liquid is introduced through the space between said second and third conduits.

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