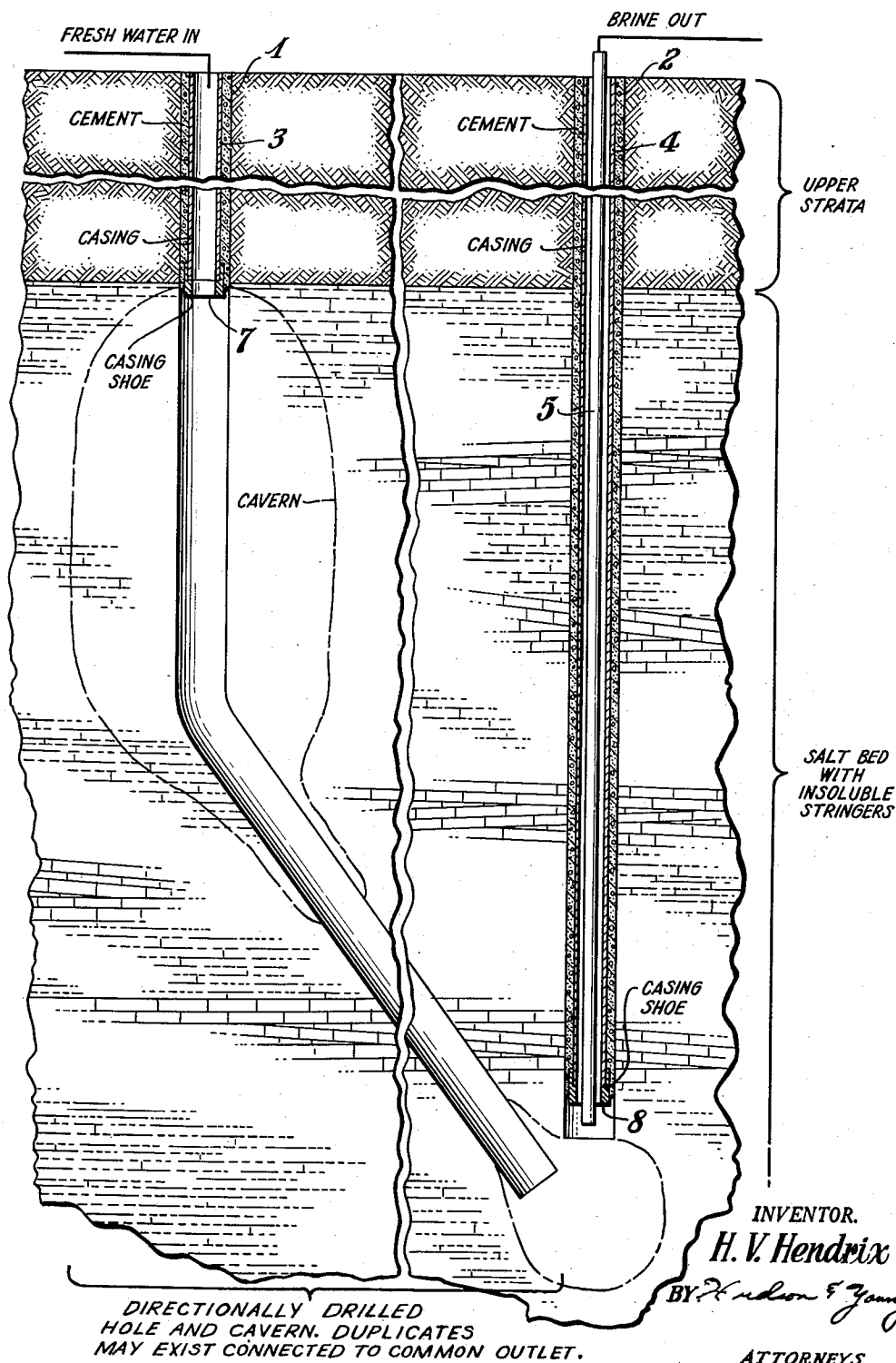


Nov. 25, 1958

H. V. HENDRIX
UNDERGROUND STORAGE CAVERN HAVING LATERALLY
SPACED WELL AND METHOD THEREFOR
Filed Dec. 28, 1953

2,861,428



1

2,861,428

UNDERGROUND STORAGE CAVERN HAVING LATERALLY SPACED WELL AND METHOD THEREFOR

Hurshel V. Hendrix, Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware

Application December 28, 1953, Serial No. 400,657

9 Claims. (Cl. 61—5)

This invention relates to an improved system of underground storage caverns for volatile fluids and to a method of making them. In its most specific aspect it relates to the preparation of a single or multi-cavern system for the underground storage of LPG (liquid petroleum gas). This is effected by establishing communication between two or more wells in a salt bed, or similar formation, by the use of directional drilling, followed by circulating a solvent through the wells to dissolve out one or more caverns.

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 (LPG) such as liquefied propane, liquefied butane, and mixtures of the two. In an effort to alleviate this storage problem, it has been a practice for some time to store 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. The advantages of underground storage over above-ground storage include: (1) lower costs, both initial and maintenance (the cost of underground storage has been estimated at about $\frac{1}{6}$ that 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.

While sites for the preparation of underground storage caverns by solvent dissolution have, as far as known, been limited to salt formations, it is believed that shale beds exist which are suitable for this purpose, since many shales disintegrate in water. It may also be feasible to dissolve space out of massive limestone with hydrochloric acid. But the extensive occurrence of salt deposits makes this type of formation a favorite for the preparation of underground storage caverns.

Salt frequently occurs as strata of varying thickness at various depths below the earth's surface. Sometimes a number of strata of the salt may occur, one above the other and separated by strata of other material such as shale, etc. In the past it has been customary to remove salt from such beds, existing a material distance below the earth's surface, by drilling isolated wells into the bed of salt in which it is desired to form a storage cavern. The well shaft is cased down to approximately or slightly below the upper surface of the salt stratum, and a tube is run down concentrically within the casing to a point near the bottom of the stratum. One of these serves as an inlet tube and the other as an outlet tube. Water is then introduced into one of the tubes in such a manner as to flood the salt bed and dissolve the salt from the bed, resulting in a substantially saturated brine, and at the same time forming a cavern. The brine formed is withdrawn through the other tube and conducted to the surface. The water may be introduced at a sufficient pressure to force the heavier brine up through the outlet tube and out through the top of the well, or an air lift or a pump may be utilized in the brine pipe. In this conventional system the brine is reused

2

to displace the LPG from the cavern thus formed; the brine, being saturated, or substantially so, will not dissolve additional salt during the displacement and, hence, no additional enlargement of the cavern occurs at this time.

However, when the buoyant force of the brine on the insoluble stringers of the cavern walls and roof is replaced by the lower buoyant force of the LPG, which occurs when the brine is displaced therewith, caving of this material frequently occurs. And, of course, some may occur during the cavern formation. As a result of this caving the brine pipes or the casing may become plugged or broken. If such caving occurs during cavern formation, the surface of the salt bed, formerly exposed to the dissolving action of the water, becomes covered up and, consequently, contact of the water with the salt is reduced to such an extent that a larger storage volume cannot be obtained. In some cases this caving may be so extensive as to necessitate an abandonment of the cavern.

An object of the present invention is to provide an improved method of forming underground caverns for fluid storage. A further object is to provide an improved underground storage system which will eliminate the hazard of losing pipes through cavings and will provide a safe place to install a pump. A further object is to provide a method of forming underground caverns which will effect more efficient salt removal. A more specific object is to develop one or more underground storage spaces in a salt bed by directional drilling to establish communication between adjacent wells and dissolution of salt from all but one well to form caverns.

In accordance with the present invention, instead of pumping water into a single shaft and removing it from the same shaft, two or more shafts are located some distance apart and are suitably connected by a channel through or beneath the salt bed. Water is then introduced through one of the shafts to dissolve salt from the salt bed, forming brine. This brine is then withdrawn through the other shaft in any suitable manner, as by pumping.

The figure illustrates a method of forming a cavern according to this invention.

The salt bed shown in the figure consists mainly of NaCl with some chlorides of potassium and magnesium interspersed with anhydrite stringers and other insoluble matter. A hole 1 is formed by drilling into the salt bed to a distance calculated to give the desired height for a storage cavern, whipstocking and drilling at an oblique angle to gain lateral distance, then drilling a second hole 2 to intercept hole 1 at the bottom. To facilitate interception a small solution cavity can be formed at the base of the directional hole, as indicated. This is accomplished by circulating water through the drill pipe string before it is pulled. Hole 1 is cased at 3 and cemented from the top of the salt bed to the surface; hole 2 is cased at 4 and cemented from the surface to the point of intercept. Hole 1 is preferably cased as soon as the drill reaches the top of the salt bed. Both casings may be provided with casing shoes 7 and 8, as shown. After the drill pipe string is pulled, fresh water is circulated into hole 1, dissolving out a cavern, as indicated, and the resulting brine is passed through the directionally drilled hole to the intercept and out at hole 2. The circulation rate should ideally be such that the brine will reach 100% saturation before it reaches the vicinity of the intercept, thus avoiding enlargement of the cavity at the base of the outlet well. While the brine may be withdrawn through case pie 4, it is preferable to set an inner, or brine, pipe 5 in hole 2 after it is cased and to withdraw the brine through this. This confines the corrosive action of the brine to said pipe, thus saving the casing.

The brine pipe can be secured by a packer set in the annular space between it and the casing at the base of hole 2.

The process is not necessarily limited to a 2-shaft arrangement since it is believed that additional directionally drilled wells can be drilled in the manner of hole 1, described above, to intercept the base of hole 2. These additional wells could then be enlarged in the manner described above to form caverns, i. e., fresh water could be circulated down through the new well and removed as brine through existing well 2. Instead of drilling a directional well first and then drilling a vertical well to intercept it, this sequence can be reversed; a vertical hole can be drilled, a cavity formed at its base by circulating water through the drill pipe string, and a second hole directionally drilled to intercept the base of the vertical hole. It is possible to arrange the channels connected with the outlet shaft in any desired manner, e. g., to radiate the channels like the spokes of a wheel with the outlet shaft at the hub position.

By effecting the removal of salt in the above manner, the most rapid solution is effected near the point at which the water enters the salt bed and as the water travels toward the outlet its salt concentration becomes greater until only relatively saturated salt solution reaches the outlet. Consequently, if any caving results from the dissolving away of salt from beneath the stratum thereabove, this caving will take place near the point of entry of the water and hence at a point remote from the removal of the brine. The solution leaving the salt bed, being relatively saturated, will dissolve away little or no salt around the base of the outlet well and, accordingly, at this point the salt bed will remain intact and minimize caving.

By operating according to the present invention a more efficient washing is effected. Since the water travels a longer distance in contact with the salt formation, a higher saturation of the salt in the circulating water is obtained. Also, since the depth of the cavern is not limited by caving difficulties, a larger storage volume is obtained.

The absence of piping from the storage cavern makes for a more dependable cavern because the difficulty of broken and/or plugged pipe which occurs when filling a conventional salt cavity is avoided. This can occur due to insoluble stringers which fall when the water is displaced with the lighter stored product, thus reducing the buoyant force on the ledge. Since, in the present invention, the water is circulated from the open salt well up through a semi-detached well cemented through the salt bed, no pipe is exposed to caving.

In addition to the advantages mentioned, the absence of caving in the vicinity of the outlet pipe has another important advantage. A safe place is provided for the installation of a down hole pump since a cased hole is provided near to the lowest point in the cavity. Using this modification, a submerged electric motor-driven pump may be placed in the lower portion of the brine outlet well to pump the LPG out of the cavern. The pump is protected since, as pointed out above, there is no danger of the pipe in the brine outlet well being broken or plugged by caving. Operating according to this modification, any stored LPG which is trapped above the casing shoe at the lower end of the cemented casing or in underground ledges in the roof can be evacuated. This is not the case when the cavern is evacuated by displacement with a brine solution; when brine is pumped into the base of the cavern to force the LPG out the top, it is obvious that if there are pockets or niches in the roof or if the casing shoe is below the roof surface some LPG will be trapped by the rising brine solution and hence cannot be evacuated in that type of system. But when the cavern is emptied of LPG by pumping it out at the base of the cavern, there is, of course, no problem of entrapment and hence more complete evacuation is possible.

In those cases where an anhydrite layer overlies the

salt formation there is no problem of the cavern roof being dissolved away, but in the absence of such a layer it is necessary to protect the roof and the foot of the casing from the solvent employed to form the cavern. To prevent dissolution of the cavern roof by the fresh water circulated downwardly through the cavern, with resultant caving, a hydrocarbon blanket may be maintained in the upper portion of the cavern. For example, LPG may be used; it will, of course, float on the surface of the water injected into the cavern being formed and thus protect the roof from the solvent action of the water. Water can be injected through a pipe extending through the surface of the hydrocarbon in the cavern or can be allowed to fall through the hydrocarbon blanket.

While a specific embodiment of the invention has been shown, the invention is not limited thereto. For example, a plurality of caverns can be formed in the manner described, all having a common outlet. While only LPG has been recited as a fluid to be stored, it is obvious that other fluids could be stored in the caverns of this invention as long as the cavern walls are substantially nonreactive therewith and insoluble therein. In place of salt formations other formations which are soluble in aqueous solution could be employed as underground storage sites. While the specific embodiment illustrates vertical shafts, the invention is not limited to these; if the cavern is located in the side of a cliff or mountain the shaft can be inclined or even horizontal. These possible variations are simply illustrative of a number which could be employed without departing from the spirit of this invention and are therefore intended to be covered.

This case is related to Serial No. 401,608, same assignee.

I claim:

1. A method for forming an underground storage cavern in a formation which is substantially soluble in aqueous solvents which comprises drilling an inlet from the surface of the earth to a point within said soluble formation, drilling at an oblique angle from said point to a deeper point in said formation, said points being laterally spaced, thereby forming a channel connecting said points, drilling an outlet well to intercept said channel at said deeper point, passing aqueous solvent into said inlet to dissolve part of the formation adjacent thereto, and removing through said outlet the resulting solution which is substantially saturated so that its dissolving action upon reaching said channel is virtually exhausted.

2. The process of claim 1 wherein the underground formation is a salt bed and the solvent is water.

3. The process of forming an underground storage cavern comprising drilling an inlet from the surface to a point in a subterranean salt bed, drilling at an oblique angle from said point to a deeper point in said salt bed to form a connecting channel, said points being separated by a substantial lateral distance, providing an outlet from said deeper point to the surface, continuously circulating water through said inlet and channel to dissolve out a cavern in the surrounding salt bed and form brine substantially 100 percent saturated before it reaches said channel, and continuously removing the brine at said outlet.

4. A process for forming an underground storage cavern in a subterranean salt bed comprising drilling an inlet well to a point within said salt bed, drilling at an oblique angle from said point to a lower point in said bed, said points being laterally spaced, thereby forming a channel connecting said points, drilling an outlet well to intercept said channel at said lower point, casing said inlet well from the top of the salt bed to the surface of the earth, casing said outlet well from a point near its base to the surface of the earth, continuously passing water through said inlet well and channel to said outlet whereby the water dissolves salt from the exposed walls of said inlet well to form a cavern and become substantially 100 percent saturated before reaching said channel, and

continuously removing the water as brine through said outlet well.

5. The process of claim 4 wherein a cavity is formed at said lower point prior to drilling the outlet well, thereby facilitating interception of the outlet well with said channel.

6. In an underground storage system, in combination, a plurality of underground caverns in a formation which is substantially soluble in aqueous solvents, individual conduit means extending from the upper portion of each cavern to the surface, said conduit means being cased and cemented to the overlying strata, a common central conduit means substantially parallel to said individual conduit means, spaced laterally therefrom, and extending from the surface to a point within the soluble formation substantially below the base of the caverns, said common conduit means being cased and cemented to the surrounding formation along substantially its entire length, and oblique, drilled channels establishing open communication between the lower portion of the caverns and the base of said second conduit means.

7. In an underground storage system, in combination, an underground cavern in a formation which is substantially soluble in aqueous solvents, first conduit means extending from the upper portion of the cavern to the surface, said conduit means being cased and cemented to the overlying strata, second conduit means substantially parallel to the first, spaced laterally therefrom, and extending from the surface to a point within the soluble formation substantially deeper than the base of the cavern, said second conduit means being cased and cemented to the surrounding formation along substantially its entire length, and an oblique, drilled channel establishing

open communication between the lower portion of the cavern and the base of said second conduit means.

8. The structure of claim 7 wherein said caverns are filled with liquid petroleum gas.

9. In an underground storage system, in combination, an underground cavern in a formation which is substantially soluble in aqueous solvents, first conduit means extending from the upper portion of the cavern to the surface, said first conduit means being cased and cemented to the overlying strata, second conduit means substantially parallel to the first, spaced laterally therefrom, and extending from the surface to a point within said soluble formation substantially deeper than the base of said cavern, said second conduit means being cased and cemented to the surrounding formation along substantially its entire length, and a channel establishing open communication between the lower portion of said cavern and the base of said second conduit means, said channel having a cross section substantially smaller than the cross section of said cavern.

References Cited in the file of this patent

UNITED STATES PATENTS

25	1,960,932	Tracy	May 29, 1934
	2,009,535	Trump	July 30, 1935
	2,161,800	Cross	June 13, 1939
	2,251,916	Cross	Aug. 12, 1941
	2,659,209	Phelps	Nov. 17, 1953
30	2,661,062	Edholm	Dec. 1, 1953

FOREIGN PATENTS

364,055	France	Aug. 13, 1906
---------	--------	---------------