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HYDRAULIC FRACTURING TO DEVELOP UNDERGROUND STORAGE CAVERNS

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2 Sheets-Sheet 1

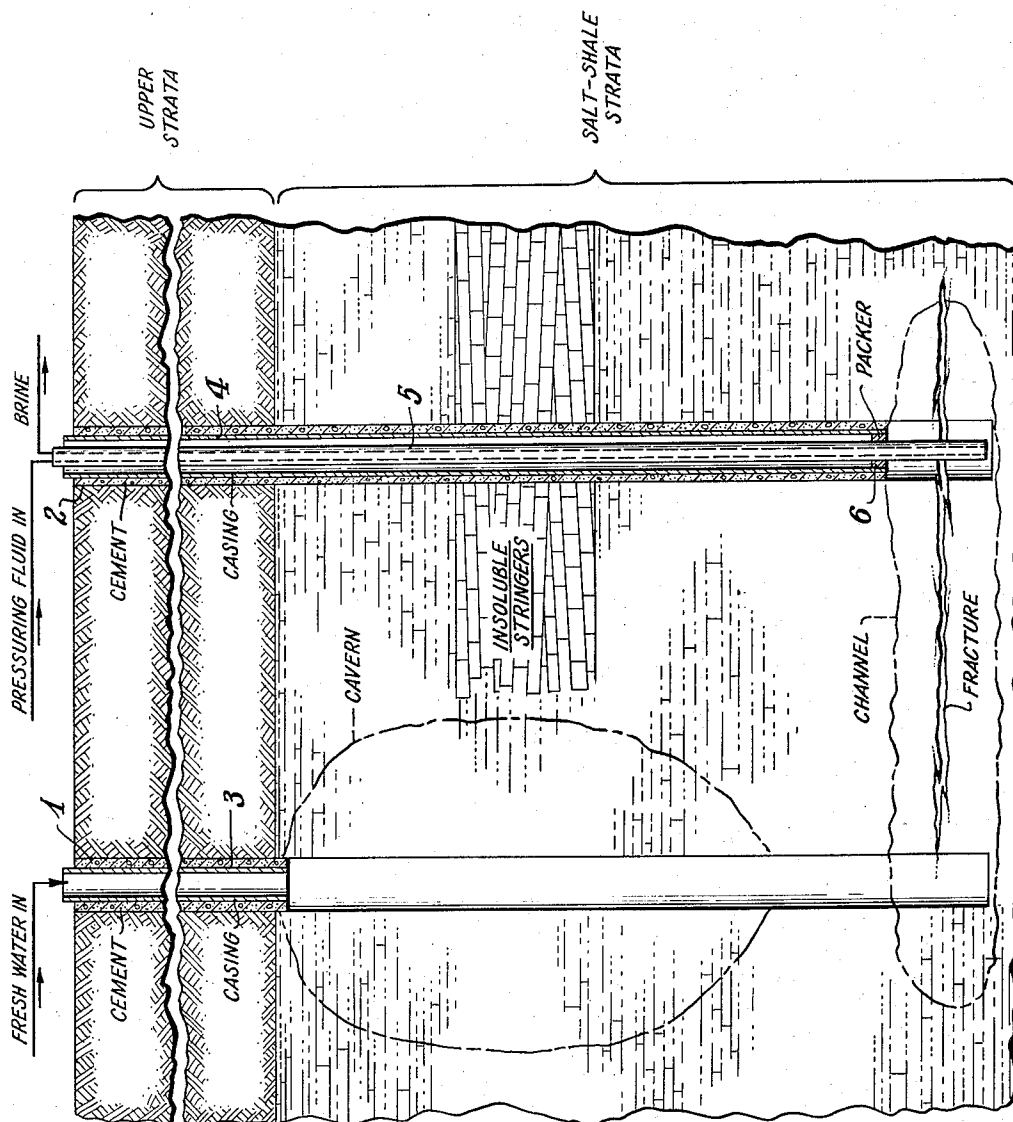


Fig. 1.

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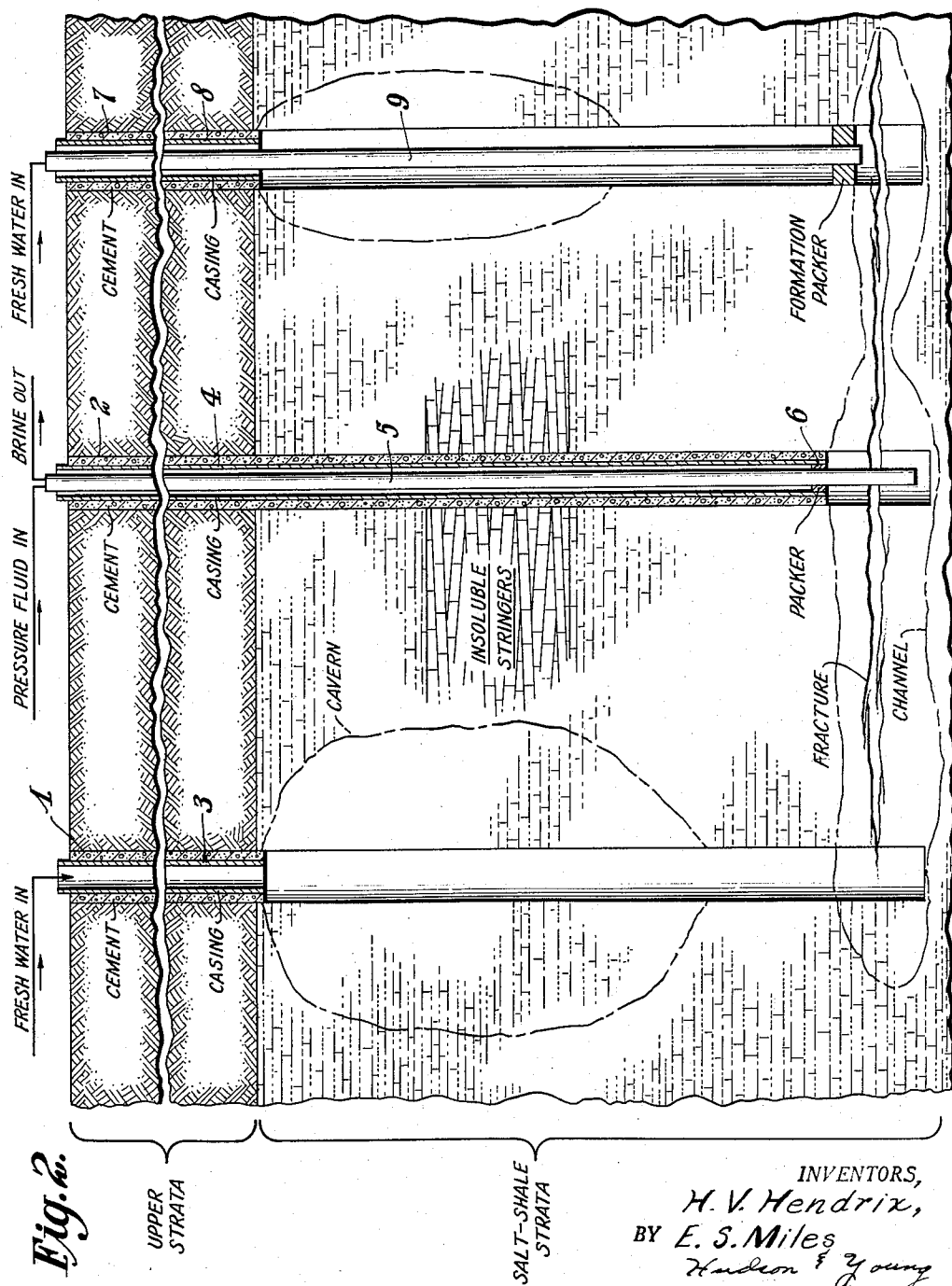
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HYDRAULIC FRACTURING TO DEVELOP UNDERGROUND STORAGE CAVERNS

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11 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 drilling two or more wells into a formation which is substantially soluble in an aqueous solution and establishing communication between them by the hydraulic fracturing of the intervening formation, followed by circulating a solvent through the wells and fracture 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 sometime 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 1/4 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 to somewhat 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

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is reused 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 caving 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 caving 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 a process comprising hydraulically fracturing the bed to establish communication between wells drilled therein, and dissolving out 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.

Figure 1 illustrates a method of forming a cavern according to this invention. Figure 2 illustrates the addition of a well to the system of Figure 1 to form an additional cavern.

Figure 1 shows a salt bed which consists mainly of NaCl with some chlorides of potassium and magnesium, interspersed with anhydrite stringers and other insoluble matter. Into this are drilled two holes 1 and 2 approximately 50 to 75 feet apart to the bottom of the salt strata. Hole 1 is provided with casing 3 from the top of the salt formation to the surface and this is cemented in. Hole 2 is provided with casing 4 from the surface to a point near the bottom and this is likewise cemented in. A brine withdrawal pipe 5 is lowered into the cased pipe in hole 2 and a packer 6 set in the annular space between the two pipes at the base of the hole. Pressure is then applied to the bottom of hole 2 by forcing an incompressible fluid, such as water, into the top of brine pipe 5. By applying the pressure required in this operation to the brine pipe 5 instead of the cased pipe 4, the possibility of fracturing the latter is eliminated. This fluid is placed under a pressure greatly in excess of the pressure existing in the salt bed resulting in fracture of the structure along a line of weakness at the base of the pipe, thus establishing communication between the lower portions of holes 1 and 2. Sufficient water is pumped into hole 2 and circulated through the fracture and hole 1 to establish a suitable channel. Then circulation is reversed; fresh water is passed through hole 1, dissolving a cavern therein as shown, and the brine is drawn

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through the channel and out through the brine pipe 5 in hole 2 to the surface.

The brine pipe 5 could be removed from hole 2 after the channel is formed, and the brine drawn up through the cased pipe 4. It is preferred, however, to leave pipe 5 in place and thus confine the corrosive action of the brine to it rather than to the cased pipe.

The process above-illustrated and described is not limited, however, to a two-shaft arrangement. Another cavern can be added to the system by drilling a new hole 7 some 50 to 75 feet from hole 2 and a sufficient distance from the periphery of the first cavern to permit equivalent enlargement of a second cavern (Figure 2). Hole 7 is cased at 8 from the surface to the top of the salt formation, then cemented, as in hole 2. An inner pipe 9 is extended to the bottom, and a formation packer 10 set in the annular space between the base of the inner pipe and the periphery of the hole. Fluid pressure is then applied to the bottom of the pipe sufficient to fracture the structure and establish communication with hole 2. The inner pipe is then pulled and the new hole 7 enlarged into a cavern in the same manner as described above in connection with hole 1; that is, by passing fresh water down through it and out hole 2 in the form of brine.

The construction of a multiple cavern unit is not limited to the method just described, however. For example, it is equally within the scope of the invention to drill a multiplicity of shafts before any fracturing is done; then when fracturing is initiated it may simultaneously connect several of these shafts with the one designated as the outlet shaft. The former can then be dissolved out in groups or individually. Any remaining unconnected wells then can be connected with the outlet shaft by individual fracturing the intervening formations in the manner described above.

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 ledges and 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. There is no initial saving in pipe cost; the real saving is in eliminating the possible loss of product and/or cavern, as well as damage to the pipe.

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 motor-driven pump may

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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 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 lower extremity of the cemented casing 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. 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 non-reactive therewith and insoluble therein. A variety of fluids could be employed in the hydraulic fracturing step. In place of salt formations other formations which are soluble in aqueous solutions could be employed as underground storage sites. Where a plurality of channels connect with the outlet shaft these can be arranged in any desired manner, e.g., the channels may radiate like the spokes of a wheel with the outlet shaft at the hub position. While the specific embodiment illustrates vertical shafts, the invention is not limited to these; if the cavern is located in a hillside 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.

We claim:

1. A method of forming an underground storage cavern comprising providing an inlet shaft and an outlet shaft to the interior of an underground formation substantially soluble in an aqueous solvent, said shafts being spaced a substantial lateral distance apart, applying a protective cover to the walls of said outlet shaft, hydraulically fracturing the intervening formation to provide a channel connecting the base of said inlet shaft to the base of said outlet shaft, said channel being entirely within said formation, passing an aqueous solvent into said inlet shaft to dissolve part of the surrounding formation above the upper level of said channel, passing the resulting substantially saturated solution through said channel, and removing the resulting substantially saturated solution through said outlet shaft.

2. The process of forming an underground storage cavern comprising providing an inlet well and an outlet well to substantially the same level in a subterranean salt bed, said outlet well being spaced a substantial lateral

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distance from said inlet well, applying a protective covering to the full length of said outlet well but only to the upper portion of the inlet well, hydraulically fracturing the intervening formation to form a channel entirely within said salt bed connecting the bases of the two wells, continuously passing an aqueous solvent through said inlet well and channel to the base of said outlet well whereby the water dissolves salt from the exposed walls of the inlet well to form substantially saturated brine, the dissolving action being confined to the exposed walls above the upper level of the channel so as to form a cavern above the upper level of said channel, and continuously removing the brine at said outlet.

3. A process for forming an underground storage cavern in a subterranean salt bed comprising drilling an inlet well and an outlet well to substantially the same level into said salt bed, said wells being spaced a substantial distance apart, casing said inlet well from the top of the salt bed to the surface of the earth, leaving the lower portion of the inlet well exposed, casing said outlet well from a point near its base to the surface of the earth, hydraulically fracturing the intervening barrier to establish a channel connecting the bases of said wells, said channel being entirely within said formation, continuously circulating water through said inlet well and channel to the base of said outlet well in an amount sufficient to dissolve salt from the exposed walls of said inlet well and thus form a cavern, said cavern being positioned above the level of the channel and continuously removing the water as brine at said outlet well, the brine having substantially no leaching action on the lower portion of the inlet well and connecting channel.

4. A process of forming an underground storage system comprising: drilling a plurality of wells into an underground formation which is substantially soluble in aqueous solutions, applying sufficient hydraulic pressure to the base of at least one of said wells to fracture the surrounding formation and thereby establish a fracture connection entirely within said formation between one well and all the other wells, casing said one well from a point near its base to the surface of the ground, casing the other wells from a point substantially above their base to the surface of the earth, thus leaving the lower portions of said other wells with unprotected walls, passing an aqueous solution through the other wells to dissolve out a portion of their unprotected walls above said fracture connection and thus form caverns, removing the solvent in substantially saturated form through the fractures to the fully cased well and through it to the surface of the ground, whereby a plurality of storage caverns are formed, the top of each communicating directly with the surface of the ground and the base of each being above and communicating with said base of the outlet well.

5. In a process for forming an underground storage cavern wherein an outlet shaft and a plurality of inlet shafts are sunk into an underground formation which is substantially soluble in an aqueous solvent and wherein said outlet shaft is cased from a point near its base to the surface of the ground, the improvement comprising the steps, in order, of sinking a first inlet shaft substantially parallel to said outlet shaft, casing said inlet shaft from the top of the formation to the surface of the ground thus leaving the lower portion of said inlet

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shaft with unprotected walls, providing a channel entirely within said formation between the base of said inlet shaft and the base of said outlet shaft by hydraulically fracturing the intervening formation, circulating solvent from said outlet shaft to enlarge said channel, passing an aqueous solvent through said inlet shaft to dissolve out a portion of the unprotected walls and thus form a cavern, the base of which is above the upper level of the channel, removing the resulting substantially saturated solvent through said channel and outlet shaft, and repeating said ordered steps to form a plurality of inlet shafts, each delineating an underground cavern situated above and communicating with the base of said outlet shaft.

6. The process of claim 5 wherein the underground formation is a salt bed and the solvent is water.

7. The process of claim 5 wherein the initial hydraulic fracture is effected by applying fluid to the base of the outlet shaft to form a fracture connecting the base of the outlet shaft to the base of the first inlet shaft.

8. The process of claim 8 wherein the subsequent hydraulic fractures are formed by applying fluid pressure to the base of each inlet shaft added to the system, thereby effecting a fracture which connects the base of said inlet shaft to the base of said outlet shaft.

9. A process of forming an underground storage cavern comprising sinking an inlet well and an outlet well to substantially the same level into a formation which is substantially soluble in an aqueous solvent, said wells being spaced a substantial lateral distance apart, lining said outlet well with a pipe of sufficient length to extend from the surface of the earth to substantially the base of the well, casing said inlet well from a point substantially above its base to the surface of the earth, leaving the lower portion exposed, hydraulically fracturing the intervening formation to form a channel entirely within said formation connecting the bases of the two wells, passing an aqueous solvent downwardly through said inlet well to dissolve out and thus laterally enlarge the upper exposed portion thereof, the leaching action being greatest where the fresh solvent contacts the formation and progressively declining toward the base of the well, using the pressure head of the fresh solvent to force the resulting substantially saturated solvent downwardly into the channel, through it to the base of the outlet well, and up through said well to the surface of the earth.

10. Process of claim 9 wherein the underground formation is a salt bed and the solvent is water, the brine thus formed having substantially no solvent action on the channel walls.

11. Processes of claim 9 wherein the continued injection of solvent causes a progressive lateral enlargement of the cavern adjacent the level at which the solvent is injected therinto.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,880,587

April 7, 1959

Hurshel V. Hendrix et al.

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

Column 6, line 18, after "fluid" insert -- pressure --; line 21, for the claim reference numeral "8" read -- 7 --; line 51, claim 11, for "Processes" read -- Process --.

Signed and sealed this 23rd day of February 1960.

(SEAL)

Attest:

KARL H. AXLINE

Attesting Officer

ROBERT C. WATSON
Commissioner of Patents