Nov. 9, 1965 S. E. SCISSON ETAL 3,216,200

UNDERGROUND PRESSURE VESSEL CONSTRUCTION METHOD

Filed July 15, 1960 4 Sheets-Sheet 1

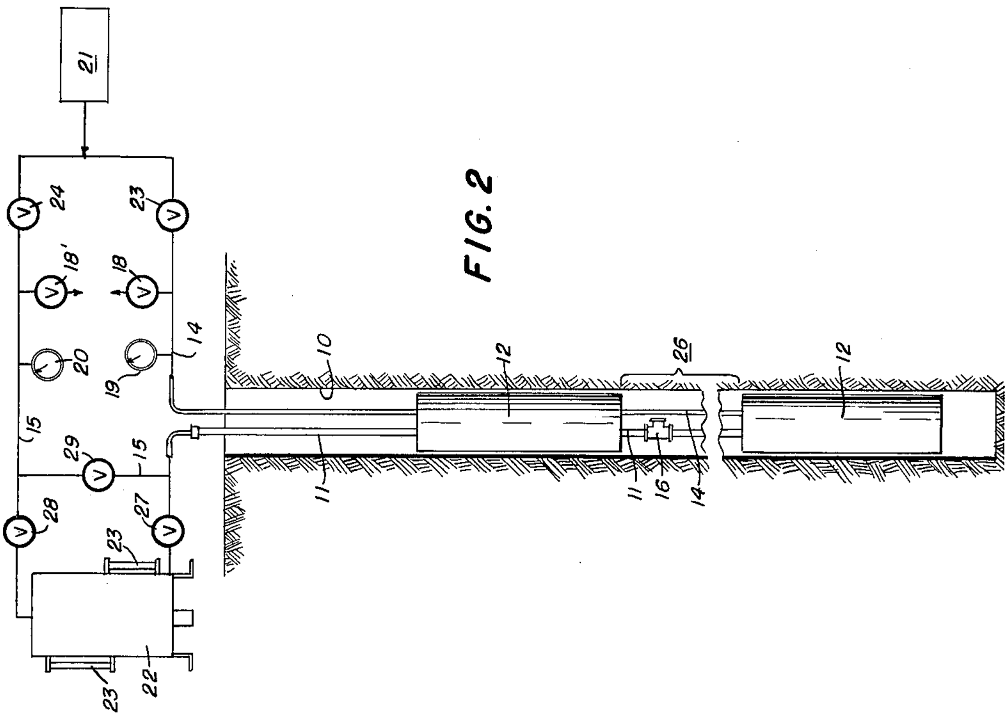

FIG. 2

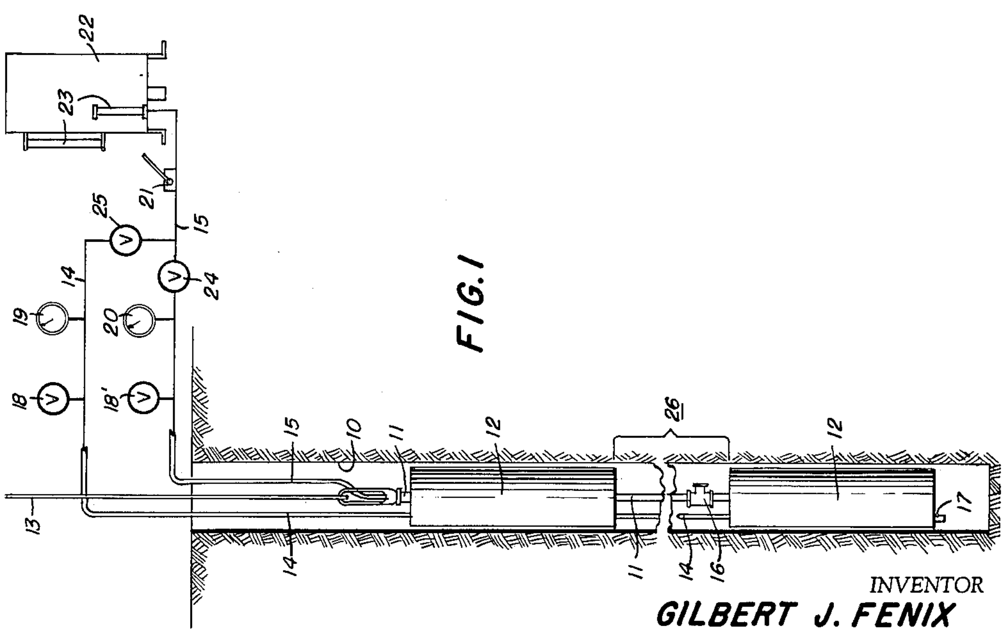

FIG. 1

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UNDERGROUND PRESSURE VESSEL CONSTRUCTION METHOD

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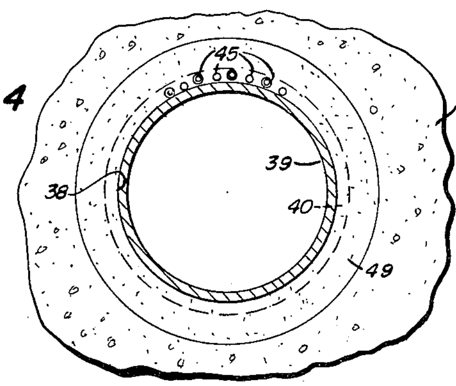
FIG.4



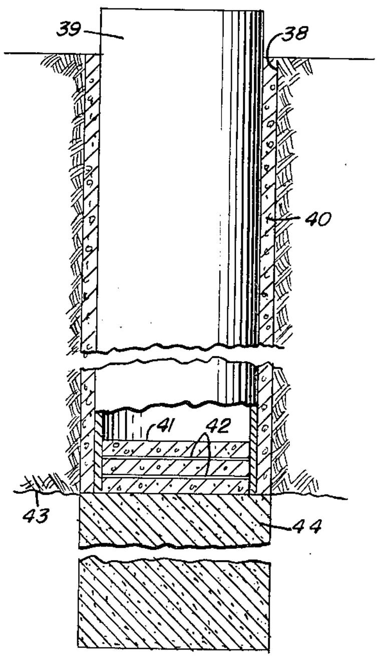


FIG.3

FIG.5

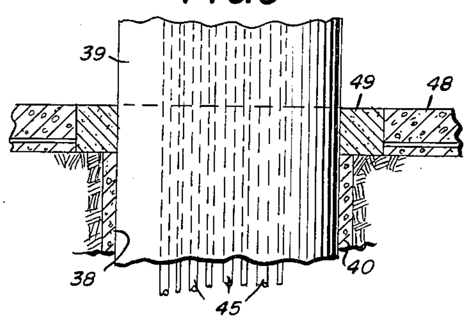
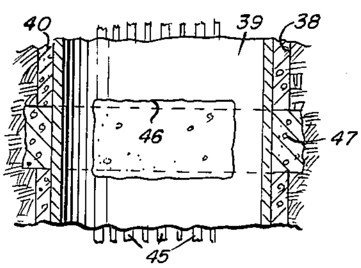


FIG.6



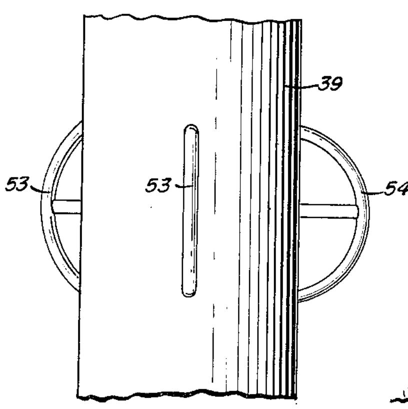


FIG.8

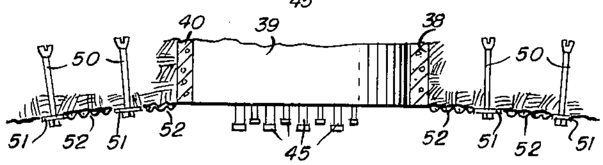


FIG.7

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UNDERGROUND PRESSURE VESSEL CONSTRUCTION METHOD

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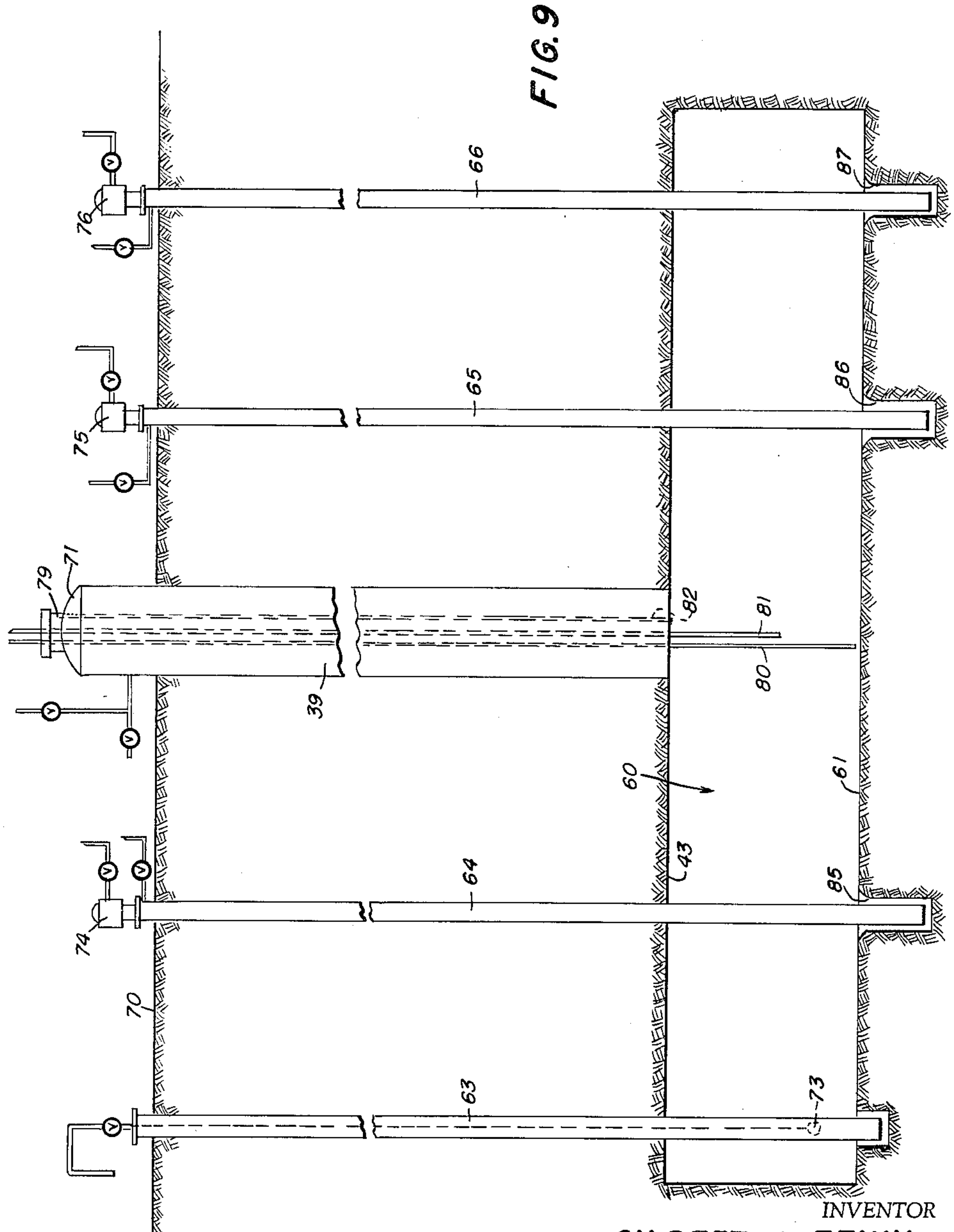

FIG. 9

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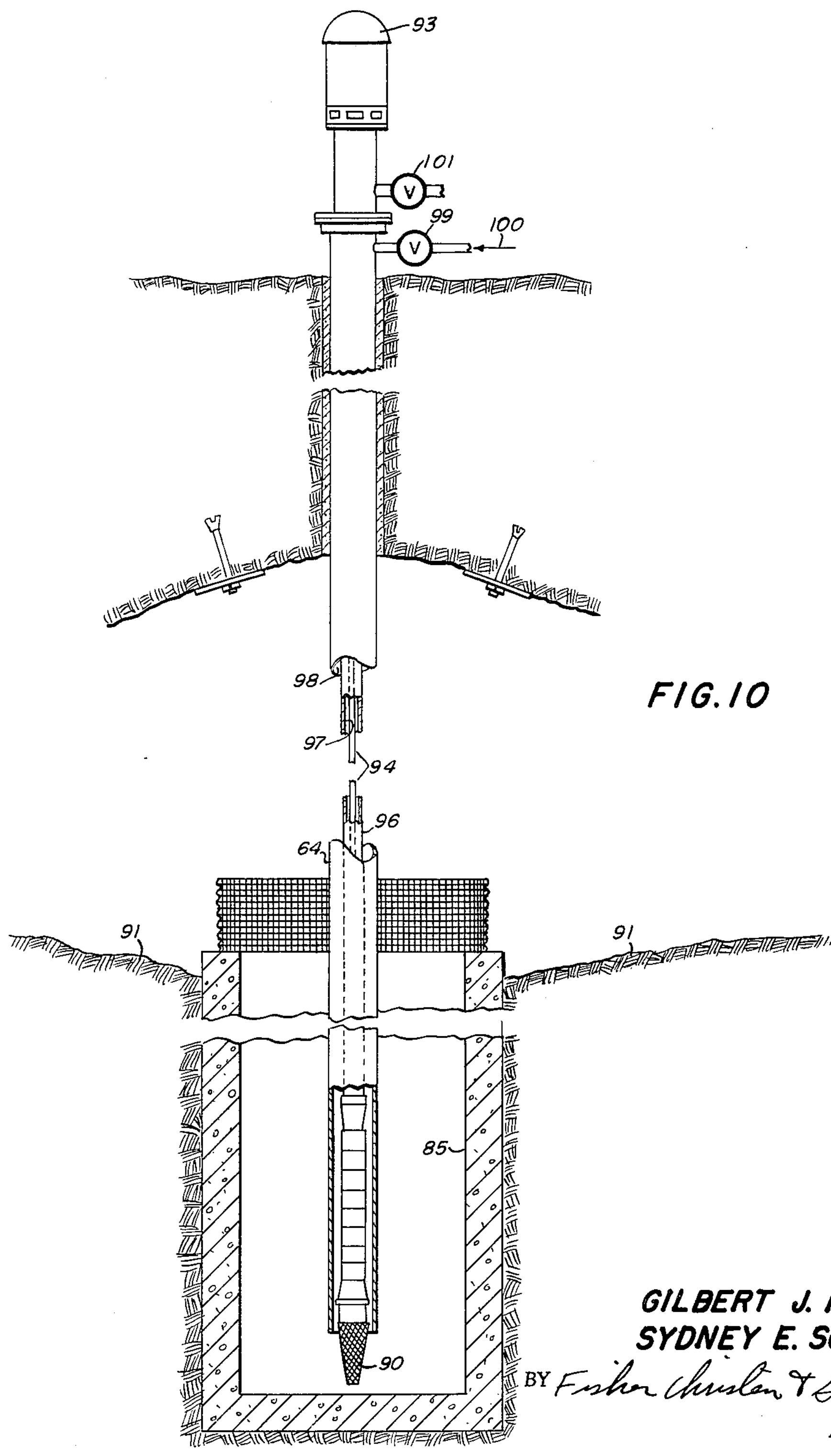

FIG. 10

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United States Patent Office

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UNDERGROUND PRESSURE VESSEL CONSTRUCTION METHOD

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Filed July 15, 1960, Ser. No. 43,100
2 Claims. (Cl. 61—40)

The present invention relates to underground storage systems and more particularly to an improved underground pressure vessel storage system and methods of location, design, and construction thereof.

Because of the numerous disadvantages inherent in the surface storage of gases and liquid, underground caverns have long been utilized to store substances such as hydrocarbon liquids and gases. For instance, storage of fluids has been effected in washed out salt cavities and in some instances, mined or dug caverns have also been constructed specifically for the storage of fluids.

Obviously the sparsity of salt deposits for fluid storage seriously limits the storage capacity available from these sources. Also, mined or dug caverns, as they were known prior to this invention, have not completely fulfilled the pressing need for storage space underground. The mining of a storage cavern is an inherently hazardous, costly and difficult operation. Only certain earth formations and strata can be used for storage and some of them only for certain fluids. The difficulties of digging the cavern, including those of the furnishing of lighting, power, air and machinery to the miners, removal of mined material, leakage of polluting foreign substances from fissures into the cavern and migration or escape of the stored fluid or gases, and many other difficulties, all combine to render previously known methods of cavern construction unsatisfactory. Frequently, for example, considerable work is accomplished toward building the storage cavern before it is discovered that the location must be disregarded due to unsatisfactory characteristics of the encountered strata because of porosity, permeability, compressive strength or reaction to the product which is to be stored. Moreover, all too frequently, serious rock fractures, which render a location unfit for storage are not discovered until much later after important expenses have already been incurred. Further, errors have been made due to improper determinations in the existing hydrostatic (ground-water) head in the area surrounding the underground storage vessel. This results in the completed vessel not having the capability of maintaining the stored product under desired or necessary pressures.

Briefly stated, the general purpose of this invention is to provide an improved underground pressure-vessel storage system, and methods of location and construction thereof, which lessen or eliminate the above described disadvantages. To attain this, the present invention conplates a unique method of location and pretesting of a proposed storage cavern site by simulating actual operational conditions on strata test zones prior to extensive mining operations. In addition, the invention provides a unique method for initiating and conducting the mining operation through an improved entrance having superior provisions for the furnishing of auxiliary power, light, etc., to the miners and incorporates an improved sealing arrangement for this entrance. The entrance casing as installed in the manner disclosed provides a barrier to surface and ground water, quicksand, etc. from gaining access to the entrance proper. In other words as each liner section is lowered into the shaft, it acts as a barrier to surface cave-ins, ground-water, seepage and the like. It is therefore an object of this invention to provide an access to the storage vessel of this invention comprising

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basically only the bored or drilled shaft and a liner insert. As a result, it is not necessary to use explosives during the construction of the access means. This is of great importance in areas where above ground storage facilities already exist.

Furthermore, by the practice of the instant invention structurally weak or fractured formations, heretofore usually considered unusable for pressure storage vessels, are rendered completely satisfactory för fluid or gaseous storage application.

Another object is to provide an improved pressure vessel system which may be installed in locations formerly considered unsuitable for underground storage.

A further object of the instant invention is to provide a unique method of excavating and otherwise constructing underground caverns for the storage of liquids, gases, solids, and/or mixtures thereof such as atomic or atomic waste materials.

Yet another object of the present invention is the provision of an improved storage system for underground storage having a great structural integrity and characterized by flexibility of operation and which is capable of construction in a relatively inexpensive and expeditious manner.

A still further important objective of this invention is to provide a method of constructing an underground storage vessel which affords maximum safety to personnel during the mining operation.

Still further, the present invention provides as an objective, an underground vessel which is substantially safer to the surrounding communities in the event of an explosion, and the likelihood of explosion is reduced due to the impossibility of personnel gaining access to the completed vessel.

Other objects and advantages of the invention will hereinafter become more fully apparent from the following description of the annexed drawings, which illustrate a preferred embodiment, and wherein:

FIG. 1 is a schematic showing of a hydraulic test apparatus suitable for pretesting rock strata for hydraulic pressure vessel characteristics;

FIG. 2 illustrates schematically, apparatus suitable for pretesting gas or hydraulic pressure characteristics of earth or rock strata;

FIG. 3 is a vertical section of the cavern entrance illustrating one manner of placing the entrance tube or liner;

FIG. 4 shows a plan view of the cavern entrance tube and pad installation of the utility conduits;

FIG. 5 is a vertical section of the entrance tube at the earth's surface illustrating the manner of surface sealing the utility conduits;

FIG. 6 is a detail view in vertical section showing the manner of sealing utility conduits and entrance tube below the earth's surface after completion of the excavations;

FIG. 7 is a vertical partial section at the lower terminus of the entrance tube showing the capped utility conduits and a method of reinforcing the cavern roof or ceiling;

FIG. 8 is a fragmentary showing of a typical entrance tube and the manner of affixing the spacing members or centralizers;

FIG. 9 schematically illustrates one typical application of the invention to an underground storage system for liquified petroleum gas and illustrates a preferred arrangement of pumping, gauging and liquid level indicating equipment; and

FIG. 10 is a section at one pumping station schematically illustrating the means provided for removing the pumps from the storage vessels after the vessels have been placed in operation.

The caverns or vessels of this invention are of the type capable of storing large quantities. The construction and mining of such vessels are huge undertakings and represent an investment of great magnitude.

Referring now to the drawings, wherein like reference numerals designate like or corresponding parts throughout the several views, there is shown in FIG. 1 the hydraulic test apparatus of the invention together with a conventional core hole **10** which may be drilled in several locations from points overlying the area to be occupied by the pressure vessel. The core samples taken are preferably examined and laboratory tested for porosity, permeability, compressive strength, reaction to product to be stored, etc., contemporaneously with the pretesting methods described hereinbelow.

Assuming a hydraulic test of zone **26** of the strata exposed by core hole **10** is desired, inflatable sealing members or packers **12** are lowered into the core hole by means of a cable **13** to the desired depth. Connected to the packers **12** through high pressure hose **14**, gauge **19**, stop valve **25** and the upper portion of line **15** is a tank of liquid **22**. To inflate the packers and thus seal off the area designated **26** for hydraulic test, venting valve **18** is opened to permit the escape of entrapped air, valve **25** is opened and valve **24** is closed. Actuation of a wobble pump **21** will fill line **14** with liquid. Vent **18** is closed and continued pumping will inflate packers **12**to desired sealing pressure. Gauge **19** records the sealing pressure in line **14** which is conveniently carried to about 75 p.s.i. above the test pressure contemplated for area or zone **26**. Valve **25** is then closed to isolate the packer sealing pressure.

The pipe **11**, which holds packers **12** in proper spaced relationship is connected to and is in communication with the interior of hose **15** which is provided with a T fitting **16**, the exposed leg of which is closed by a rupturable disc. The provision of the disc, it will be appreciated, provides a convenient seal to keep the line free of dirt and also ensures a leakage test for fittings, hoses and pipes up to the designed rupture pressure of the disc.

To pressurize the core hole in test zone **26**, vent **18'** in line **15** is cracked or opened and water or other test liquid is pumped by pump **21** through opened valve **24** to fill the line **15**. Closure of vent **18'** permits pressure build-up by pump **21** in line **15** and pipe **11** against the disc in T connection **16**. By building up a desired pressure and discontinuing the pumping, gauge **20** may be observed for pressure loss indicating fitting or hose leakage. Continued pumping will rupture the disc in T connection **16** and the zone **26** will be subjected to hydraulic pressure test of any desired amount. By closing valve **24**, the pressure in area **26** (represented on gauge **20**) may be observed for drop-off indicating leakage in the formation. Any leakage can readily be quantitized with the described apparatus merely by opening valve **24**, pumping additional liquid to hold the desired pressure and recording the liquid drop. This may conveniently be done with such apparatus as sight glasses **23**.

To deflate and remove the packers on completion of the test it is usually only necessary to crack vent **18**. However, under some conditions, as, for instance, when static water level is low or near the packers **12**, the packers may not deflate when valve **18** is opened. To facilitate removal of the packers in this situation another repturable disc **17** is located in the extreme terminus of line **14**. This disc, it should be understood, is considerably stronger than the disc located in T connection **16**. However, closure of valve **18** and continued pumping will cause it to rupture, deflating the packers and spilling liquid into the core hole **10**. The apparatus may then be readily removed from the core hole.

FIG. 2 illustrates a test apparatus suitable for gas and/or hydraulic pretesting. The test area is again designated **26** for clarity though it should be understood that many areas in the same or in different core holes may be tested by either hydraulic or gas methods or both. This determination being one dictated by the geological conditions encountered and the requirements of the storage system to be constructed.

Packers **12** may be lowered as described hereinbefore and inflated by opening valve **25** to connected pressurized gas source **21** with high pressure line **14**. Valves **24** and **18** should, of course, be closed for proper pressure build-up in the packers. When a suitable sealing pressure is registered on gauge **19**, valves **25** and **18** are closed and valves **24** and **29** opened. Valves **28** and **27** are normally closed except as described hereinafter. Gas pressure from source **21** then builds up in line **15** against the disc in T connection **16** in pipe **11**, as described hereinbefore, and the test is performed in a similar fashion to the hydraulic test described in connection with FIG. 1, the test pressure exerted on area **26** being computable from the gauge pressure shown on gauge **20**.

If it is desired to measure the amount of loss in gallons at area **26**, if such exists, the liquid tank **22** may be used. Valve **29** is closed and valves **27** and **28** are opened. Any loss can then be measured at sight glasses **23** while desired pressure readings are maintained at gauges **19** and **20**. Upon completing tests, pressure may be released by closing the gas source stop valve and opening valves **18'** and **18** in that order.

Having arrived at a suitable location for the pressure vessel on the basis of design considerations and the test results discussed hereinabove, an entrance to the proposed cavern is begun by drilling a shaft or hole **38**, as illustrated in FIG. 3. The shaft length will be determined by considerations understood by those skilled in the art, but according to the invention, the drilled shaft extends through the roof **43** of the cavern to be excavated to a point well into the vessel, and the shaft extension is filled with sand **44**. A steel liner or tube **39**, having a diameter of sufficient size to permit extraction of mined material from the vessel, and facilitating ingress and egress of personnel and machinery, is next installed. The liner must also be of sufficient strength to withstand grouting and hydrostatic pressure on the outside thereof and gas pressure on its interior. It should be noted here that the tremendous amount of material which must be excavated will be removed through this single shaft.

Assuming, for illustrative purposes, that the drilling rig is not strong enough to hold the liner **39**, provision is herein made to enable the liner to be floated into place. In this instance, the first liner section may be provided with brass rods **42** welded to the lower opening of the bottom line to facilitate supporting a concrete floating plug **41** which is poured into the liner section. The brass rods are easily severed when it is desired to remove the plug.

As shown in FIGS 4–7 a plurality of utility conduits or lines **45** are suitably fastened to the exterior surface of the liner **39**, as by welding, and are capped, at the first liner section as clearly shown in FIG. 7.

In order to leave the interior of the liner **39** free from all obstructions the liner sections are preferably beveled at their abutting surfaces on the exterior liner circumference and are welded together on the outside. This feature becomes exceedingly important during the actual mining operation. Huge material removal buckets travel at great speeds through the liner. In addition, successive lengths of utility conduits **45** are added and fastened, as by welding, on the outside of the liner sections as the whole liner **39**, is assembled and lowered into the shaft **38**.

To facilitate the welding, handling lugs (not shown) are preferably affixed to each liner section so it may be supported above ground for welding. As each section of the liner or tube **39** is welded to the preceding section, radially extending centralizers or spacers **53** and **54** are attached in circumferentially spaced relation around the liner. These spacers are for the purpose of holding the liner or tube 39 in an upright and spaced relation in the drilled shaft or hole 38 so that a predetermined space is available for grouting the tube 39 into the shaft 38.

As will be evident from a perusal of FIG. 8, the spacers designated 54 may be substantially more arcuate and thus extend further from the lever 39 than the spacers 53. The more arcuate spacers 54 are placed on the same side of the liner as the utility conduits, such arrangement being considered preferable to ensure that the grout used to hold and seal the liner will completely enclose the entire liner and the utility conduits, and to protect the utility conduits while being lowered into the shaft.

When a concrete plug 41 has been poured in the tube bottom, in instances in which the liner is to be placed by floating, water is added to the inside of the liner causing it to sink as each line section with its utility conduits, and centralizers are added. After the liner is completely assembled and is resting on sand 44, the space between the liner 39 and the drilled shaft 38 is grouted with a Portland cement grout 40 or other suitable grouting materials to permanently fasten and seal the liner 39 in the shaft 38. At this time, the entrance slab 48 may conveniently be poured, leaving an annular section 49 through which conduits 45 pass at the surface free of concrete. The annular section 49 may be filled with sand.

After the grout 40 has hardened, the water used to sink the liner sections is removed and the plug 41 and rods 42 are drilled out. Sand 44 and any water remaining in the shaft extension vacated by the removal of sand 44 may be removed by conventional drilling equipment.

Mining or excavating the cavern proper, according to the invention, is begun at the top of the intended pressure vessel. By so beginning, the material dislodged by blasting or other means will fall naturally into the void created by the removal of sand 44 leaving room for the miners to work and load excavated material for removal through liner 39. In this manner one of the perennial problems of underground excavation is simply and effectively overcome. By removing the caps from the utility conduits 45, electrical lines, air, water, telephone lines and the like can be readily made available in the cavern while the liner 39 has its interior completely unobstructed and smooth to facilitate the removal of excavated rocks and earth and for the free ingress and egress of men and equipment to the cavern being mined.

The particular manner of digging the pressure vessel other than as herein specified is dependent upon considerations too numerous to be considered here. Suffice it to say that any conventional method may be employed —the room and pillar method for instance, being one well suited for most requirements.

Upon completing the excavation of the vessel the entrance liner is permanently sealed. Utility lines 45 are again capped at the cavern roof 43 and sections 46 of the liner are cut out as shown in FIG. 6. The depth below the surface at which sections 46 of the liner are removed may vary according to the application of the invention. For instance the section cuts are made at the strongest and most impermeable stratas determined by the original pretesting steps.

Referring again to FIG. 6, at the removed section 46, the utility conduits 45 are cut out, the grout 40 is removed, and material is removed to solid surface for a grout seal 47. Sections of the liner 39 are welded back into position and grout is pumped into the space 47 through one utility conduit with the others open at the top. Pumping is continued until the grout comes out through the other utility conduits thus forming a seal under pressure of the column of grout from the surface to the liner area illustrated in FIG. 6. Additional pressure is applied at the surface if deemed necessary.

The sand filling in annular space 49 is removed, the utility conduits are trimmed, if required, and the annular space 49 filled with concrete completing the upper seal for the liner 39. As may be seen from FIG. 9, the liner 39 then has a cap 79 welded or otherwise suitably fastened on to permanently seal this section of the pressure vessel.

In the underground mining of pressure vessels, structurally weak rock formations are sometimes encountered, that in their natural or fractured condition are unsuitable for fluid or gas storage. Should this condition be encountered, the surfaces may be reinforced as shown in FIG. 7, by the use of expansion bolts 50, plates 51 and/or the use of mesh 52. The placement of these reinforcing members, of course, are made along side surfaces as well as those of the roof as shown. Proper control of the sizes and shape of the vessel and the use of reinforcing means such as those illustrated frequently make possible the utilization of otherwise objectionable earth formations for storage purposes. The expansion bolts 50 may be from 4 to 10 feet in length and are inserted in bores which extend beyond the fracture to solid rock.

It has also been found in practicing the invention that fractured formations that are not competent in their natural state can be sealed to hold products by pressure grouting. A preferred method of accomplishing this desirable result involves drilling a hole or holes from within the cavern to intersect the offending fracture at a predetermined distance from the cavern surface. The distance to the point of intersection from the cavern surface may vary depending upon the severity of the fracture. Packers or sealing members are inserted in the drilled hole and grout is introduced under pressure to seal the fracture. It will be understood that the extent of the pressure grouting of a fractured area usually deemed necessary to hold water inflow, for instance, to acceptable quantities, will vary depending on such factors as the hydrostatic pressure of the ground water, the design pressure of the vessel and the product to be stored. It should be remembered that during the mining and grouting phase of construction, there is no interior pressure from the stored gas counteracting the hydrostatic head. After the stored fluid is placed in the container, a balance is struck between the head and interior pressure which will, in fact, aid in preventing leakage from the vessel.

The final design of the pressure vessel system, as will be understood from the description thus far, may take a variety of forms and perform many storage functions. In FIG. 9 there is schematically illustrated one typical application of the invention adapted for the underground storage of liquefied petroleum (LP) gas. It should be clearly understood that the particular arrangement illustrated, including the shape of the pressure vessel, the location and number of shafts, pumps, etc. is intended as illustrative and should not be interpreted as limitative in any respect. The cavern 60 is illustrated as having a generally rectangular shape with horizontal roof 43 and substantially horizontal floor 61.

Four auxiliary shafts, 63, 64, 65 and 66 provide communication between the surface 70 and the pressure vessel 60 and house a liquid float level 73 and three conventional LP gas pumping units 74, 75, and 76, respectively. The main liner 39 is provided with a gauging unit 79 which may include three indicator tubes 80, 81 and 82 accurately positioned at predetermined and different heights from the cavern floor and which may be connected to a suitable manometer. As will be apparent, the state of the LP storage is at all times evident to an observer at the surface through the combined readings available from the liquid float indicator 73 and the gauging unit associated with the liner 39.

Upon completion of mining operations, pumping sumps 85, 86 and 87 of suitable depths are drilled in the bottom of the vessel positioned so as to receive casings 64, 65, and 66, respectively. The casings extend to a point near, but spaced from, the bottom of the sump. Pumps 90 are installed within each casing to remove any water which finds its way into the vessel, or to pump the storage area of the stored fluid, if desired. Note in FIGURE 10 how the lower surface **91** of the vessel is sloped toward the pumping sumps.

One of the serious problems encountered in sealed vessels of the type described, is the removal of these pumps for inspection and repair. The manner of overcoming this difficulty is shown best by the structure taught in FIG. 10.

As seen, the casing **64** extends from a surface turbine **93** to near the bottom of sump **85**. The pump line shaft **94** connects the lower rotating elements **90** and turbine **93** for furnishing movement to said lower elements. Surrounding the line shaft is an intermediate casing **96** defining an annulus **97** with the shaft **94**. The annulus **97** provides a pumping column.

An annulus **98**, formed between the casing **64** and the casing **96**, is connected with a gate valve **99** which controls a water supply **100**.

When it is desired to remove the pumping elements **90** from the vessel, the pump discharge valve **101** is closed, and the valve **99** is opened. Source **100** provides, through valve **99**, a column of water to the annulus **98**. When the column of water in **98** reaches a sufficient height to counteract the LPG pressure within the vessel, valve **99** may be closed and the pump may be pulled. The column of water within casing **64** effects a seal to prevent the escape of the stored gas.

After repair and inspection, the pump is lowered into its regular position, valve **99** is closed and valve **101** is opened and the excess water in the column is pumped out in the normal manner.

The necessary height for the column of water can be determined from known factors, and will be apparent to those skilled in the art.

Thus it will be seen that an improved underground presure vessel storage system is constructed which may be adapted for the storage of many products. Improved methods of construction are used which render ordinarily unsuitable locations satisfactory for the storage of a wide variety of substances. In addition, an early determination of suitability or unsuitability of a site may be made by a pretesting procedure which simulates with a high degree of authenticity actual operational conditions of storage prior to extensive and costly mining operations.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described and illustrated.

We claim:

1. In a method of sealing a liner to a surrounding horizontal strata at an intermediate level in a vertical access shaft for an underground pressure reservoir, the steps of joining a plurality of utility conduits to the exterior periphery of a liner in a lengthwise direction prior to introducing the liner into the shaft, positioning said liner vertically in the shaft, grouting the space between the liner and shaft, maintaining the interior of said conduits clear during emplacement of the liner in the shaft, removing a portion of said liner and said conduits at the level where the seal is to be made, removing the grouting and loose earth materials at said level, closing the opening in the liner, closing said conduits below the level of the seal, and introducing sealing material to said level from the surface through one of said conduits.

2. In the method defined in claim **1** the additional step of continuing the introduction of sealing material through one conduit until said material fills the space around the liner and is returned to the surface through another of said conduits.

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