

Sept. 1, 1959

E. E. REED

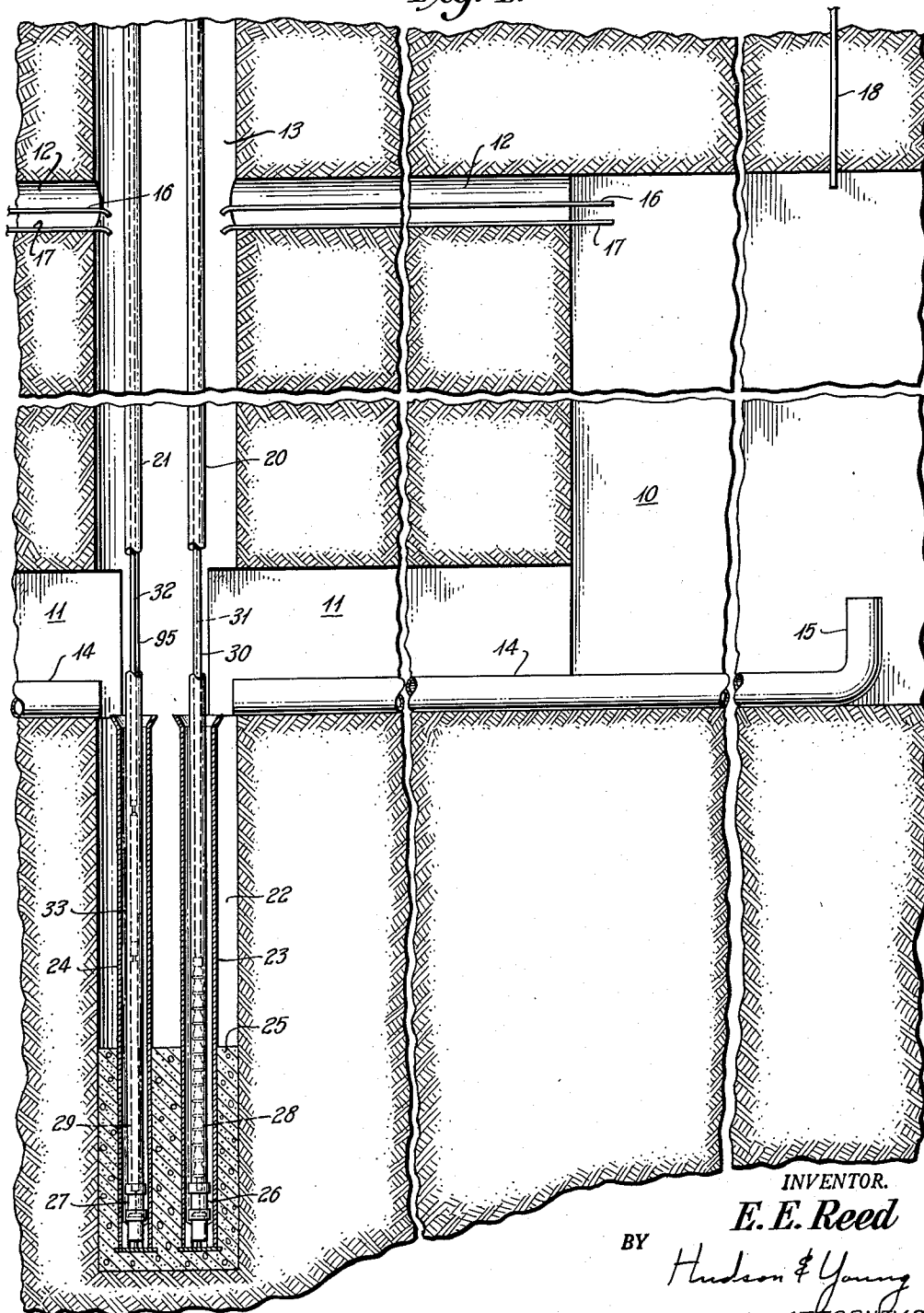
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PRESSURIZED STORAGE SYSTEM

Filed April 13, 1953

4 Sheets-Sheet 1

*Fig. 1.*



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Fig. 3.

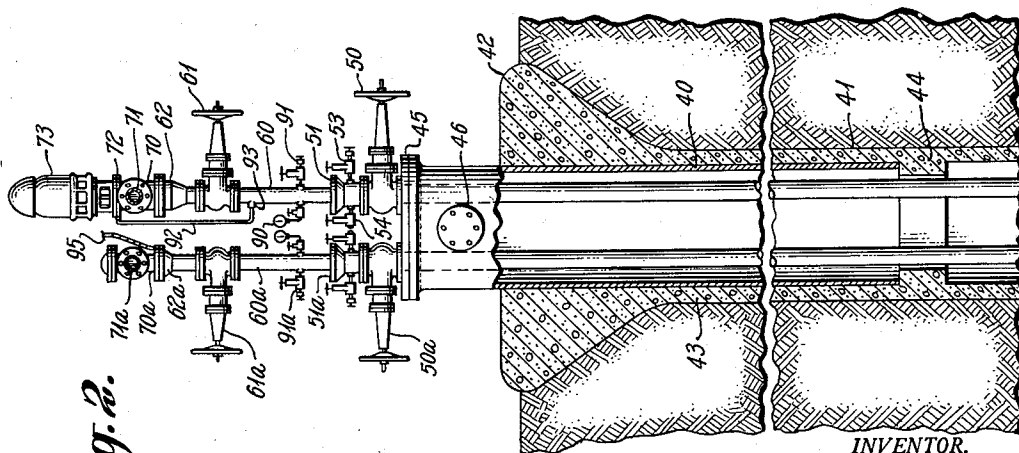
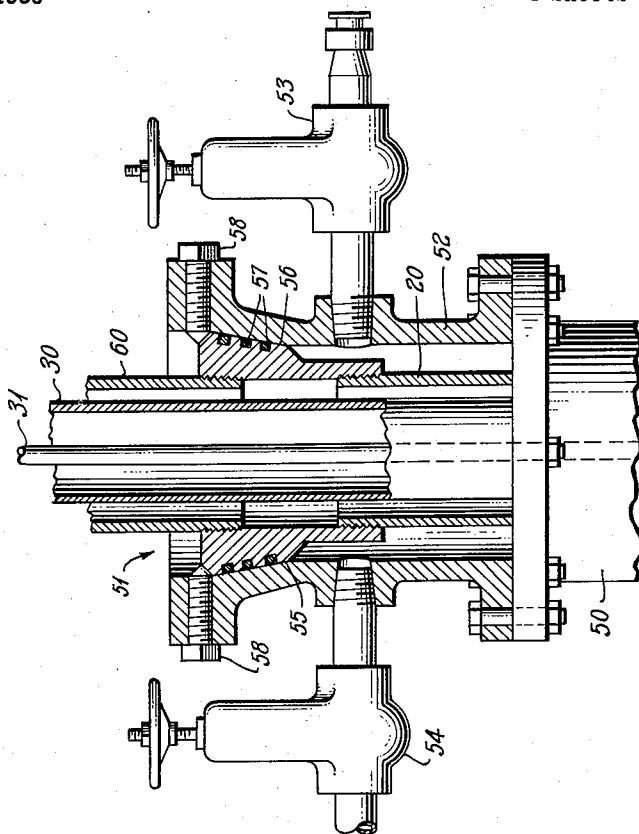


Fig. 2.

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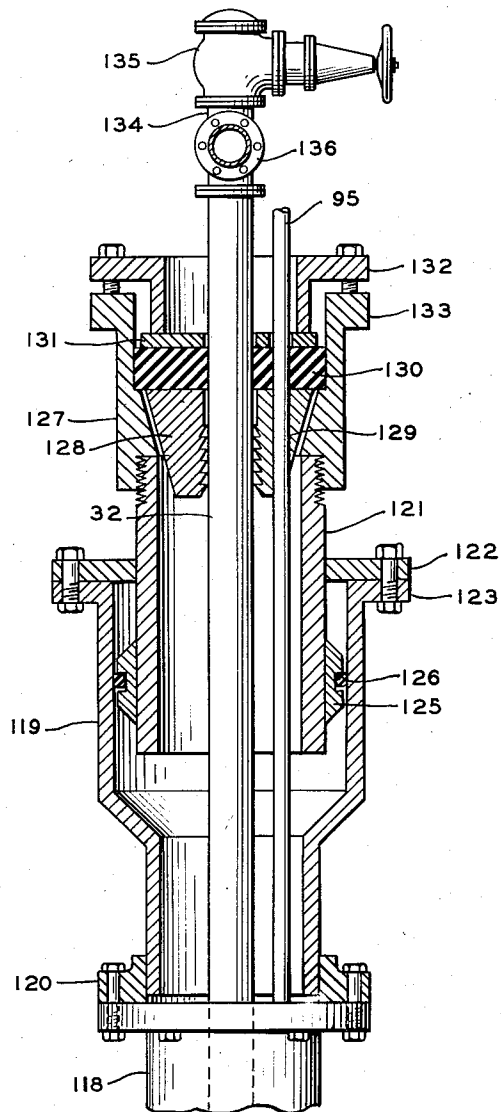


FIG. 9

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## PRESSURIZED STORAGE SYSTEM

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Application April 13, 1953, Serial No. 348,344

8 Claims. (Cl. 61—5)

This invention relates to an improved pressurized storage system and a method of operating same. In one of its aspects this invention relates to an improved underground storage system for storing liquefied gases under pressure. In another of its aspects this invention relates to a method of inserting and withdrawing a pump from a pressurized container without loss of vapors from high vapor pressure products stored therein.

This invention is directed in part to apparatus for the storage and removal from storage of liquefied gases and in a preferred modification is directed to the underground storage of liquefied petroleum gas. The constantly expanding production of liquefied petroleum gas has created a definite problem in providing suitable storage facilities for this material. Due to the high pressure of liquefied petroleum gas, particularly propane, the cost of storage in surface equipment, such as steel tanks, becomes excessive due to the massive construction required to withstand the vapor pressure in a safe manner. This problem becomes extremely acute where it is necessary to store large quantities of such materials during the off season.

In order to overcome some of these difficulties, it has been proposed to store liquefied petroleum gas in porous water bearing formations, in water-leached caverns in salt formations or in abandoned mines in impermeable shale or in limestone formations. Further, underground concrete storage tanks and buried sections of pipe have been used to a limited extent in the storage of liquefied petroleum gas.

In accordance with a preferred embodiment of this invention, an underground storage system for liquefied petroleum gas is provided which is capable of storing extremely large quantities of this material at a very small unit cost. Further, a number of operating and safety features are provided to insure a long period of trouble-free operation of the storage system, together with easy and reliable introduction of the material into storage and removal of material therefrom. The storage system is not limited to storage of liquefied petroleum gas, but is applicable to the storage of any liquefiable gas such as ammonia, carbon dioxide, and the like. Further, the present invention is not necessarily limited to underground storage systems and can be employed where steel tanks are used as the pressurized storage container.

There are many methods of removing liquefied gas from a storage container. For example, it is well known that a liquefied gas can be forced from a chamber by introducing compressed gas above the liquid. In other instances, displacement by a second non-contaminating liquid of greater density can be employed. One method, and a more generally preferred method, for removing a liquefied gas from storage is by means of a centrifugal pump. The pump is usually contained within the pressurized container and can be one wherein the motor driving the pump is also submerged, or of the type driven by a rotating shaft attached to a motor on the outside of the container. It is recognized that such pumps will have to be pulled from the container from time to time for

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repair or replacement. To do this, some means must be provided to prevent the loss of large quantities of vapor from the container. In order that the container can be tightly sealed during the time the pump is being operated or being inserted or withdrawn, I have devised a system and method which will be described in terms of one preferred modification, namely the storage in underground chambers of liquefied petroleum gas.

It is an object of this invention to provide an improved pressurized storage system and method of operating same.

It is another object of this invention to provide an improved underground storage system for storing liquefied gases under pressure.

It is still a further object of this invention to provide an underground storage system capable of storing liquefied gases having a high vapor pressure for an extended period with a minimum of operating difficulties.

A still further object of this invention is to provide a method for introducing and withdrawing a pump from a pressurized storage container without loss of vapors from high pressure products stored therein.

Various other objects, advantages and features of the invention will become apparent from the following detailed description taken in conjunction with the accompanying drawing, in which:

Figure 1 is a vertical sectional view, partly in elevation, of part of an underground storage system constructed in accordance with this invention;

Figure 2 is an enlarged vertical sectional view, partially in elevation, of the top portion of the shaft of Figure 1;

Figure 3 is an enlarged vertical sectional view, partially in elevation, of a casing head;

Figure 4 is an enlarged vertical sectional view, partially in elevation, of a tubing head and a slip joint for a submerged pump driven by means of a shaft extending to a motor at the surface;

Figure 5 is a vertical sectional view, partially in elevation, of a pump and downhole valve unit;

Figure 6 is a sectional view taken along the line 6—6 of Figure 5, looking in the direction of the arrows;

Figure 7 is an enlarged vertical sectional view, partially in elevation, of a tubing head and slip joint for a submerged pump actuated by electrical means extending from the surface to the motor unit, also submerged;

Figure 8 is a sectional view taken along the line 8—8 of Figure 7 looking in the direction of the arrows; and

Figure 9 is a vertical sectional view of the modified form of tubing head and casing head.

Referring now to Figure 1 of the drawing in detail, according to a preferred modification of my invention, an underground storage system of the present invention includes at least one storage cavern which contains at least one chamber 10. The caverns can be constructed in a variety of different ways as illustrated in the copending application of Leonard P. Meade, Serial No. 314,541, filed October 13, 1952, and now abandoned, which copending application also discloses a preferred modification of the present invention. For example, a single large cave can be excavated, or a number of smaller caves can be formed and interconnected in any suitable manner. As shown large chamber 10 communicates by means of tunnels 11 and 12 with an enlarged vertical shaft 13 extending from the surface of the earth to a region adjacent the cavern. Other caverns in the system are not shown in the drawing. The storage chambers can be of any geometric shape.

Disposed in each tunnel 11 is a drain pipe or header 14, and the headers of all the caverns extend through the respective tunnels and communicate with the shaft 13. Each storage chamber is provided with a drain pipe 15 which at its lower end is connected to the header 14 and which extends upwardly into the associated storage cham-

ber 10. Thus, should the tunnel 11 become choked with rock or dirt due, for example, to caving, the main storage portion of the chamber still communicates with the shaft through its associated pipe 15 and header 14. As a result, should caving occur while fluid is stored within the chamber the fluid can drain out through the described pipe and header, and the main storage portion of the chamber is available for further service even when caving occurs.

Although such drain pipes are very advantageous in many installations, they may not be required in cases where the formation is not subject to caving.

Forming a part of each cavern is an upper tunnel 12, each upper tunnel being connected to one of the storage chambers 10 and communicating with shaft 13. Disposed in each tunnel 12 are a pair of vent pipes 16 and 17 communicating with shaft 13 and the adjacent chamber 10. The purpose of these vent pipes is to provide venting of the entire underground storage system to equalize pressure throughout. It will be evident that, if desired, tunnel sections 12 can be eliminated and the described communication between the upper part of the storage chambers and the shaft can be effected solely by the vent pipes 16 and 17. Conversely, the vent pipes 16, 17 could be eliminated and venting effected through the tunnel. Where different types of caverns are used any suitable means can be employed to equalize the vapor pressure above the liquid to be stored in the various caverns or storage chambers of the system. One or more of the caverns is provided with a drilled hole 18 extending from the surface of the earth to the top of the associated cavern through which material is introduced into the system for storage. The filling mechanism at the surface, not shown, is of a nature to prevent loss of pressure from the system. Suitable mechanism is illustrated in the aforementioned copending application of Leonard P. Meade, Serial No. 314,541.

The shaft 13 incorporates pump mechanisms to be hereinafter described in detail for lifting the stored fluid from the bottom of the shaft to the surface from whence it is passed to transportation and marketing outlets, or other desired use. In operation, therefore, the material to be stored is introduced into the top region of the caverns by filling means 18, or such filling means or pipe can extend to the bottom of the cavern. Material withdrawn from storage flows through the lower tunnel 11 and/or the header 14 to the shaft 13 where it is lifted to the surface for use as described. Materials such as liquefied petroleum gas have a high vapor pressure and the thickness of the earth layer above the caverns is effective in containing this high vapor pressure without the use of steel tanks or a lining for the cavern. In one specific embodiment of the invention, the storage chambers are formed in an impermeable shale formation, whereby a long period of trouble-free operation is assured.

Referring again to Figure 1, two strings 20 and 21 of casing extend from the surface of the earth through means hereinafter described and the lower portion of shaft 13 into a well 22 formed at the bottom of the shaft. It will be noted that the well 22 is below the level of the tunnels 11 and caverns so that fluid can flow from each one of the storage chambers into the well. At the bottom of the well, the casing strings 20 and 21 are received within enlarged sections 23 and 24, respectively, of pipe which are anchored in a mass 25 of cement at the bottom of the well. Disposed at the lower ends of casing strings 20 and 21 are valves 26 and 27 respectively, and immediately above these valves are pumping units 28 and 33. Pump 28 is a multiple stage pump supported within casing 20 by means of tubing 30 and driven by rod 31 extending through tubing 30 to the surface. Pump 33 is supported within casing 21 by means of tubing 32 and incorporates a motor 29 which is actuated by a suitable electrical current source at the surface. Both pumps are actuatable

to lift the fluid stored within the system through the shaft to the surface.

Referring now to Figure 2 of the drawing, it will be noted that an enlarged tubular metal liner 40 formed, for example, from steel is provided at the top of the shaft and this liner is anchored by a mass 41 of cement disposed about the exterior of the liner. The liner extends a substantial distance downward in the shaft, if desired, or to a location just above the upper tunnels 12 for the purpose of supporting the walls of the shaft and substantially or completely eliminating the flow of water or other liquids into the shaft. The liner, of course, also prevents the escape of the stored material. The mass of cement includes an enlarged rounded upper section 42 adjacent the surface of the earth and supporting and anchoring the liner 40, a generally cylindrical portion 43 surrounding the body of the liner 40, and a lower inwardly protruding portion 44 adjacent the bottom of the liner. The top of the liner protrudes a short distance above the earth and is closed by an enlarged flat plate or well head 45. It will be evident that the liner 40, well head 45 and mass 41 of cement constitute collectively means for sealing the shaft 13 at a region above the level of the lower tunnels 11 and upper tunnels 12. A manhole closed by a cover 46 is provided in the liner 40 for access into the storage system for any desired purpose.

With respect to pump 28, it will be noted that the casing string, tubing string, and drive rod all extend upwardly through the shaft 13, the liner 40, and the well head 45 to the surface, where these parts all pass through a valve 50, Figure 2, on top of the well head. Immediately above valve 50 is a head 51 from which the casing string is hung. Referring to Figure 3, it will be noted that the casing head includes a generally cylindrical body 52 bolted to an adjacent flange of valve 50 and provided with valved connections 53 and 54. The upper end of casing string 20 is threaded to a tapered annular block 55 which engages a complementary tapered surface 56 of the body 52, the block being provided with a plurality of sealing gaskets 57 and held in position by bolts 58. The gaskets 57 seal the region between the body 52 and casing string 20, this region communicating through valve 50 with the top portion of shaft 13. A pipe 60 is threaded to the top of block 55, this pipe extending upwardly to and supporting a valve 61, Figure 2. The tubing string 30 with its concentric drive rod 31 extends through pipe 60 and valve 61 to a combination tubing head and slip joint 62, the detailed construction of which is shown by Figure 4.

Referring to Figure 4, it will be noted that the tubing head includes a generally cylindrical body 63, the lower end of which rests upon and is supported by an adjacent flange of valve 61. The upper end of the tubing 30 is threaded to a flanged block 64 which is bolted to a flange 65 secured to the body 63. An annular member 66 fits between the body 63 and the tubing 30, this member being provided with an annular sealing gasket 67. Secured to the flange block 64 is a pipe 70 communicating with the interior of the tubing and provided with an outlet conduit 71. Immediately above this conduit is a sealing member 72 through which extends drive rod 31 of the pump, this rod being driven by an electric motor 73, Figure 2, at the top of the assembly.

In assembling and operating the apparatus, valve 50 is opened and the casing string is hung from casing head 51 so that it extends downwardly through valve 50 to its position within the pipe 23, Figure 1. Attached to the lower end of the casing is the valve 26 which is normally closed so that, once the casing is inserted and the casing head sealed, no material can pass through casing to the surface nor between the casing and the body 52. Thereupon, the tubing string and drive rod are lowered into the well section by section, it being understood that the pump 28 is secured to the lowermost section of tubing. This process continues until the pump is disposed a short

distance above the valve 26, at which time the annular member 66, Figure 4, and sealing gasket 67 are positioned at the upper end of the cylindrical body section containing them, and the flanged block 64 with its attached pipe 70 is positioned a short distance above the cooperating flanged member 65. At this time, the interior of the casing is pressurized as by connecting valves 53 and 91, Figure 2, that is, the pressure in the casing is equalized with the pressure in the underground storage system. Thereupon, the tubing is lowered to its final position, thereby causing the pump body to engage the valve 26 and open it. Due to the annular member 66 and sealing gasket 67, the vapor in the casing cannot escape during the period when the tubing and pump are lowered into the final operating position, at which time the flanged block 64 is bolted to the part 65 and the system is sealed.

Thereafter, when the motor 73 is energized, the resulting rotation of rod 31 and pump 28 lifts fluid to the surface of the storage chamber.

Referring to Figures 1, 5 and 6, it will be noted that fluid passes into the pipe 23 from the tunnels 11 and headers 14 leading to the storage chambers. From the bottom of the pipe 23 fluid enters a lower section 80, Figure 5, of the valve 26, this valve section being centered by a series of vanes 81 protruding from the wall of the pipe 23. The valve 26 further includes a valve head 82 engageable with a valve seat 83 in an upper section 84 of the valve. The valve head is mounted upon a stem 85 which passes through a spider 86 and cooperates with a spring 87 urging the valves towards closed position. When the pump is positioned above the valve, as indicated by solid lines in Figure 5, the valve is closed by the action of spring 87 and no fluid can enter the casing from the lower section 80 of the valve. However, when the pump is lowered into its operating position, as indicated by the dotted lines in Figure 5, the valve stem 85 is displaced by the pump body and the valve is opened, thereby allowing the fluid to pass through the valve to the pump intake in the casing. The pump, thereupon, lifts the fluid through the tubing, the surface structure 50, 61, and 62, Figure 2, and to and out through discharge conduit 71, Figure 4.

Should it be necessary to remove the pump for servicing, the flanged block 64, Figure 4, is detached from flange 65, and the tubing 30 is lifted a short distance so that the pump body, Figure 5, moves out of engagement with valve stem 85 and closes the valve, thereby sealing the lower end of the casing. Any fluid pressure existing in the casing can then be removed or bled by venting the interior of the casing to the atmosphere, it being understood that the interspace between the tubing and the casing is sealed by annular ring 66, Figure 4, and gasket 67, while the tubing is being raised a sufficient distance as to allow the valve to close. It will be noted that pipe 60 is provided with a pressure gage assembly 90, Figure 2, and a valved pipe 91, the described bleeding being effected by a hose from valve 91 to a suitable vent pipe. After the pressure has been vented, the tubing section and the drive rod section can be readily lifted and removed with resultant lifting of the pump 28 out of the shaft. When the removal is completed, valve 61 can be closed to provide a positive seal implementing the seal produced by the downhole valve 26, Figure 5. A line 92, Figure 2, which extends from an opening 93 in pipe 60 communicating with the casing to the seal assembly 72 allows liquid from the seal to drain back into the system.

Many features of construction of the pump unit and casing string 21 are similar to those described in connection with the pump unit and casing string 20. In this construction, the motor 29, Figure 1, is downhole, and is mechanically connected to pump 33. The casing string 21 and the tubing string 32 supporting the pump-motor assembly extend upwardly through the shaft 13, the liner 40, and the well head 45 through a valve 50a, a casing head 51a, a pipe 60a, and a valve 61a corresponding in

structure and function to the similarly numbered parts described in connection with the casing string 20. Positioned above valve 61a is a tubing head and slip joint 62a which is similar to tubing head 62 but which is modified as will hereinafter be described to provide for electrical leads 95 which supply power to motor 29.

Electric power is supplied to motor 29 by said leads 95 from a suitable source of current, not shown, said leads extending upwardly through the interspace between casing 21, Figure 1, and tubing 32 and thence through pipe 60a and tubing head 62a to the surface. The downhole valve 27 is similar in construction and operation to the valve 26 so that the casing string and tubing string can be inserted into or removed from the shaft 13 in the manner described in connection with the tubing 30 and casing 20. When the pump is energized by application of a suitable electric current to electric motor 29, fluid flowing from the storage chamber through tunnel 11 or header 14 passes downwardly through pipe 24 and, then, upwardly through valve 27, the pump unit and the tubing 32 to the surface, whence it is removed through outlet conduit 71a.

Referring to Figures 7 and 8, tubing head 62a is modified to provide for electrical leads 95 which pass to motor 29 through the annular space between tubing 32 and casing 21. The seal is maintained by means of an annular member 100 and a gasket 101. However, to provide for the passage of leads 95 through annular member 100, said member is split along the line 102, Figure 8, and lead 95 is held tightly in place by screws 103. It will be noted that the steel sheathing covering the insulation may be stripped from the electrical leads 95 from a point below annular member 100 and above the outlet of said leads from tubing head 62a through flange 64a. If desired, a short length of pipe can be secured to flange 64a, this pipe being concentric with and surrounding tubing 32. The cable can then pass between pipe 32 and this additional length of pipe so that there is no necessity of it passing through member 100.

Electrical leads 95 leave tubing head 62a through hole 110 in flange 64a. A seal is maintained around said leads 95 by means of a gasket 111, held in place by means of plate 112 and screws 113. It will be appreciated that removal of leads 95 from annular member 100 and from flange 64a may be facilitated by providing said leads 95 with suitable socket connections which can be easily engaged and disengaged.

An alternative and preferred construction for the motor-pump unit 29 is shown in Figure 9. In this figure, casing string 24 terminates, at the upper end thereof, in an upper section 118 which is flanged to a member 119 of similar construction to the member 63 of Figure 4, the flanged connection being denoted by reference numeral 120. Fitting within the member 119 is a short piece of pipe 121 carrying a flange 122 which is bolted to a flange 123 at the top of member 119. The lower end of pipe 121 carries an annular member 125 fitting between the pipe 121 and member 119, the annular member 125 being provided with an annular sealing gasket 126. At the upper end of pipe 121 is threaded a tubing head 127 incorporating slips 128 supporting the tubing string 32.

Slips 128 are constructed and arranged to define a passage 129 for the cable 95. A rubber packing ring 130 is mounted above the slips 128, this packing ring being provided with openings for the passage of tubing string 32 and cable 95, and being compressible by a cap 131 engageable by a pressure member 132 bolted to a flange 133 at the top of the tubing head 127. At the uppermost portion thereof, the tubing string 32 is provided with a T-section 134, one portion of the T having a valve 135 secured thereto and the other portion 136 of the T leading to a suitable outlet for the stored fluid.

It will be evident that, when it is desired to remove the pump for servicing, flange 122, 123 can be unbolted

and the tubing string together with tubing head 127 and pipe 121 lifted a short distance so as to close downhole valve 127, Figure 1, without breaking the seal at annular member 126. When the downhole valve is closed, the fluid can be bled from the interspace between the tubing and casing, after which the casing and pump can be lifted out section by section until it reaches the surface. The advantage of the construction of Figure 9 is that the initial lifting of the tubing does not cause the tubing to move upwardly through the packing ring 130 which might result in damage to the packing ring from the frictional engagement of the tubing therewith. After the downhole valve has been closed, the tubing head can, of course be readily disassembled without injury to the packing ring and without the escape of fluid from the underground storage system. Similarly, upon replacing the pump, annular member 126 seals the casing as the tubing string and pump are lowered into engagement with the downhole valve for resumption of operation of the storage system.

In its broadest aspect, this invention is directed to a method for withdrawing a pump from a pressurized container without loss of pressure therein, said container being provided with a conduit extending through a boundary of said container and closably communicating with said container, said pump being positioned within said conduit adjacent the region of communication of said conduit with said container, by partially withdrawing said pump from said conduit and thereby concomitantly closing off said conduit from said container, releasing the pressure within said conduit, and thereafter completely withdrawing said pump from said conduit.

While this invention has been described and exemplified in terms of its preferred embodiment, those skilled in the art will appreciate that modifications may be made without departing from the spirit and scope of said invention.

I claim:

1. In a pressurized storage system for holding a volatile liquid under pressure comprising a closed container which when in use has liquid stored therein, an improved access for removal of said liquid with a pump which access enables said pump to be removed from or inserted into said liquid without loss of pressure within said container comprising, in combination, a first conduit extending from outside said container to a point normally within said liquid within said container, said first conduit being closed in that portion within said container and sealed to said container around said first conduit's periphery at its point of entry into said container; a check valve in that portion of said first conduit within said liquid and biased in the closed position by the pressure within said container; a second conduit disposed longitudinally within said first conduit; a pump at the end of said second conduit and within said first conduit, said pump being within the vicinity of said valve and having its outlet connected to said second conduit, said pump being movable with said second conduit for insertion into or removal from said first conduit; a slip joint providing a seal between said first and second conduits to form a closed zone containing said pump and closably communicating with the space inside said container through said valve and communicating with the space outside said container through said pump and thence through said second conduit, said slip joint permitting limited longitudinal movement of said second conduit within said first conduit without breaking said seal said movement being sufficient to open and close said valve as subsequently described; and a bearing member contacting said valve and positioned in the path of said pump so that said valve is forced into the open position when said second conduit is moved within the distance permitted by said slip joint from a first sealed position to a second sealed position farther within said first conduit and said

valve is permitted to seat when said second conduit is returned to said first sealed position.

2. In a pressurized underground storage system for holding a volatile liquid under pressure comprising an underground storage cavern which when in use has liquid stored therein, an improved access for removal of said liquid with a pump which access enables said pump to be removed from or inserted into said liquid without loss of pressure within said cavern comprising, in combination, a first conduit extending from outside said cavern to a point normally within said liquid within said cavern, said first conduit being closed in that portion within said cavern and sealed to said cavern around said first conduit's periphery at its point of entry into said cavern; a check valve in that portion of said first conduit within said liquid and biased in the closed position by the pressure within said cavern; a second conduit disposed longitudinally within said first conduit; a pump at the end of said second conduit and within said first conduit; said pump being within the vicinity of said valve and having its outlet connected to said second conduit, said pump being movable with said second conduit for insertion into or removal from said first conduit; a slip joint providing a seal between said first and second conduits to form a closed zone containing said pump and closably communicating with the space inside said cavern through said valve and communicating with the space outside said cavern through said pump and thence through said second conduit, said slip joint permitting limited longitudinal movement of said second conduit within said first conduit without breaking said seal, said movement being sufficient to open and close said valve as subsequently described; and a bearing member contacting said valve and positioned in the path of said pump so that said valve is forced into the open position when said second conduit is moved within the distance permitted by said slip joint from a first sealed position to a second sealed position farther within said first conduit and said valve is permitted to seat when said second conduit is returned to said first sealed position.

3. In a pressurized underground storage system for holding a volatile liquid under pressure comprising a closed underground storage cavern which when in use has liquid stored therein, an enlarged vertical shaft extending from the surface of the earth to the region adjacent to said cavern, a tunnel connecting said shaft with the bottom region of said cavern, means for introducing liquid to be stored in said cavern, and means including a wellhead for sealing said shaft above the level of said tunnel, an improved access for removal of said liquid with a pump, which access enables said pump to be removed from or inserted into said shaft without loss of pressure within said storage cavern comprising, in combination, a tubular casing extending from the surface of the earth through said wellhead and said shaft to a position below the level of the lower region of said cavern, said casing being closed in that portion within said shaft and sealed to said wellhead around said casing's periphery; a casinghead mounted on said wellhead and supporting said casing at the top of the shaft; a check valve in the lower portion of said casing, said check valve being biased in the closed position by the pressure within said cavern; tubing disposed concentrically within said casing; means supporting said tubing at the top of said shaft; a pump at the end of said tubing and within said casing, said pump being within the vicinity of said valve and having its outlet connected to said tubing, said pump being movable with said tubing for insertion into or removal from said casing; a slip joint providing a seal between said casing and said tubing to form a closed zone containing said pump and closably communicating with the space inside said shaft through said valve and communicating with the space outside said shaft through said pump and through said tubing, said slip joint permitting limited longitudinal movement of said tubing within said

casing without breaking said seal, said movement being sufficient to open and close said valve as subsequently described; a bearing member contacting said valve and positioned in path of said pump so that said valve is forced into the open position when said tubing is moved within the distance permitted by said slip joint from a first sealed position to a second sealed position farther within said casing and said valve is permitted to seat when said tubing is returned to said first sealed position; and means for actuating said pump.

4. A storage system according to claim 3 wherein said pump actuating means includes a rod extending through said tubing and operatively connected to said pump, and a motor at the surface of the earth operatively connected to said rod.

5. A storage system according to claim 3 wherein said pump actuating means includes an electric motor disposed in said casing immediately adjacent said pump and operatively connected thereto, leads extending through the interspace between the tubing and casing from the surface of earth to said motor, and means for supplying electrical current to said leads to energize said motor.

6. In a pressurized underground storage system for holding a volatile liquid under pressure comprising a closed underground storage cavern which when in use has liquid stored therein, an enlarged vertical shaft extending from the surface of the earth to the region adjacent to said cavern, a tunnel connecting said shaft with the bottom region of said cavern, and means for sealing said shaft above the level of said tunnel, an improved access for removal of said liquid by pumping, which access enables a pump to be removed from or inserted into said shaft without loss of pressure within said storage cavern comprising, in combination, a pair of strings of tubular casing extending from the surface of the earth through said shaft to a position below the level of the lower region of said cavern, said strings of casing being closed in that portion within said shaft and sealed to said shaft around their peripheries at said sealing means; two check valves, one in the lower portion of each of said casing strings, said check valves being biased in the closed position by the pressure within said cavern; two lengths of tubing, one disposed concentrically within each of said strings of casing; a pair of pumps, one pump at the end of each of said length of tubing and within each string of casing, said pumps being within the vicinity of said valves and each pump having its outlet connected to a length of tubing, each of said pumps being movable with its length of tubing for insertion into or removal from its string of casing; a pair of slip joints, each slip joint providing a seal between one string of casing and its concentrically positioned length of tubing to form a closed zone containing a pump, and closably communicating with the space inside the shaft through the valve in said casing and communicating with the space outside said shaft through the pump and connected tubing, each slip joint permitting limited longitudinal movement of the tubing within the casing without breaking the seal, said movement being sufficient to open and close the valve as subsequently described; a pair of bearing members, each member contacting a valve and positioned in the path of each pump so that each valve is forced into the open position when the tubing within the casing is moved within the distance permitted by its associated slip joint from a first sealed position to a second sealed position farther within the casing and each valve is permitted to seat when the tubing in the associated casing is returned to said first sealed position; and means for actuating each of said pumps.

7. A storage system according to claim 6 wherein one of said pumps is actuated by a rod extending through its tubing to a power source on the surface and the other of

said pumps is actuated by a motor positioned adjacent the pump in the casing.

8. In a pressurized underground storage system for holding a volatile liquid under pressure comprising a closed underground storage cavern which when in use has liquid stored therein, an enlarged vertical shaft extending from the surface of the earth to a level below the bottom region of said cavern whereby a well is formed in said shaft below the level of said cavern, a lower tunnel connecting said shaft immediately above said well with the bottom region of said cavern, an upper tunnel connecting said shaft with the upper region of said cavern, a vent pipe disposed in said upper tunnel, one end of said vent pipe communicating with said cavern and the other end communicating with said shaft, a filler pipe extending from the surface of the earth to the top region of said cavern to introduce fluid to be stored into the cavern and means for sealing said shaft above the level of said tunnels including a tubular liner at the top of said shaft, a mass of cement anchoring said liner in position in the earth, and a wellhead closing the top of said tubular liner, an improved access for removal of said liquid with a pump, which access enables said pump to be removed from or inserted into said shaft without loss of pressure within said storage cavern comprising, in combination, a tubular casing extending from the surface of the earth through said wellhead and said shaft into said well, said casing being closed in that portion within said shaft and well; a first valve surrounding said casing and positioned on said wellhead; a casing head mounted on top of said first valve and supporting said casing at the top of the shaft; tubing disposed concentrically within said casing; a second valve mounted above said casing head surrounding said tubing; a tubing head disposed above said second valve; a pump supported by said tubing at the bottom of said casing in said well, said pump having its outlet connected to said tubing and being movable with said tubing for insertion into or removal from said casing; a check valve at the bottom of said casing in said well, said check valve being biased in the closed position by the pressure within said cavern; a slip joint providing a seal between said casing and said tubing to form a closed zone containing said pump and closably communicating with the space inside said well through said check valve and communicating with the space outside said shaft through said pump and tubing, said slip joint permitting limited longitudinal movement of said tubing within said casing without breaking said seal, said movement being sufficient to open and close said check valve as subsequently described; a bearing member contacting said check valve and positioned in the path of said pump so that said check valve is forced into the open position when said tubing is lowered within the distance permitted by said slip joint from a first sealed position to a second sealed position and said check valve is permitted to seat when said tubing is raised to said first sealed position; means connecting the top portion of said tubing to a discharge line; and means for actuating said pump.

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