April 28, 1959 E. S. MILES 2,883,833

UNDERGROUND STORAGE SYSTEM AND METHOD OF OPERATING

Filed Jan. 22, 1954 3 Sheets-Sheet 1

Fig. 2.

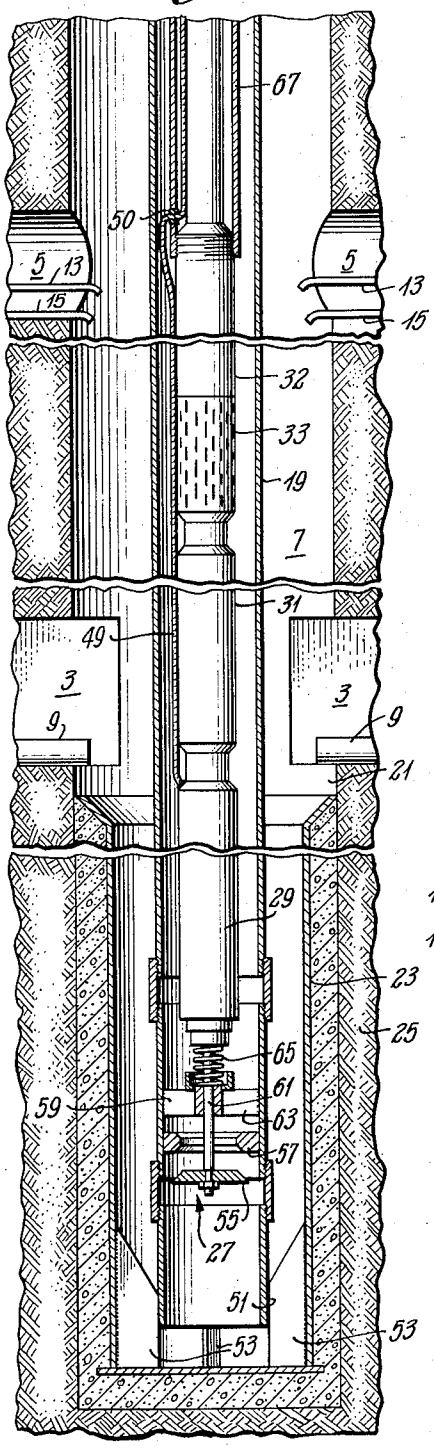
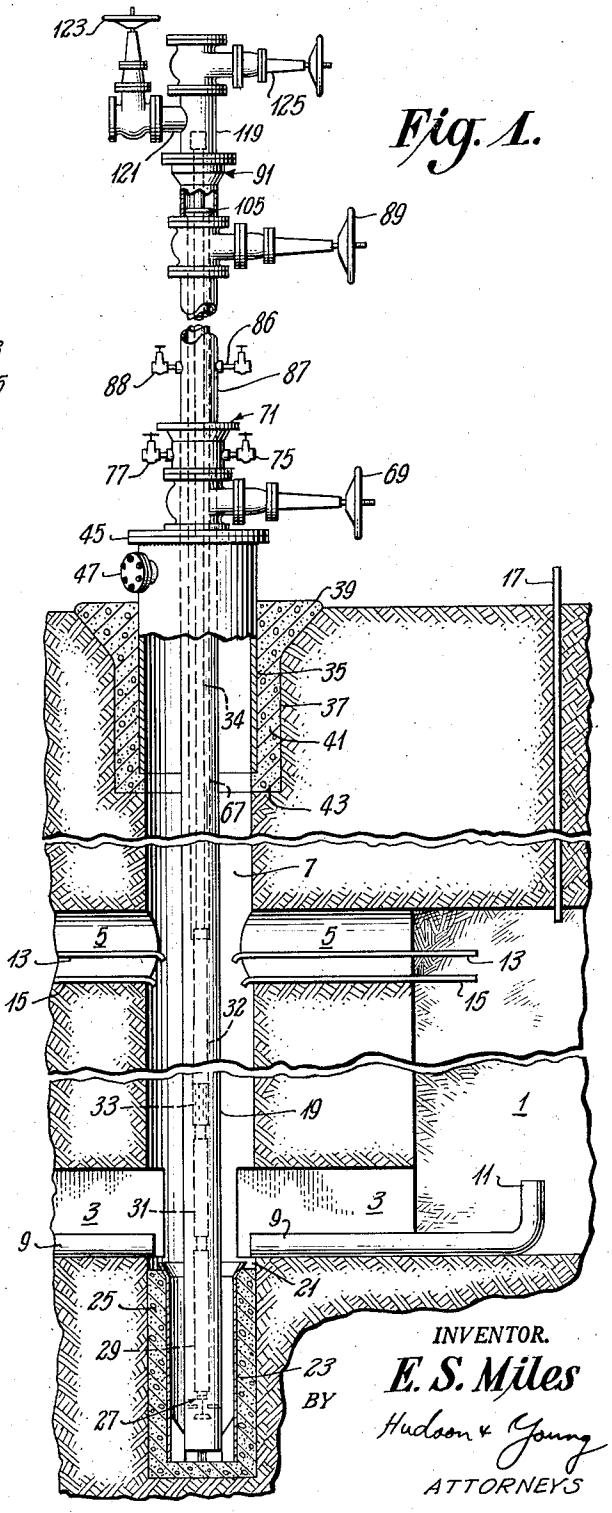


Fig. 1.



INVENTOR.
E. S. Miles
BY
Hudson & Young
ATTORNEYS

April 28, 1959 E. S. MILES 2,883,833

UNDERGROUND STORAGE SYSTEM AND METHOD OF OPERATING

Filed Jan. 22, 1954 3 Sheets-Sheet 2

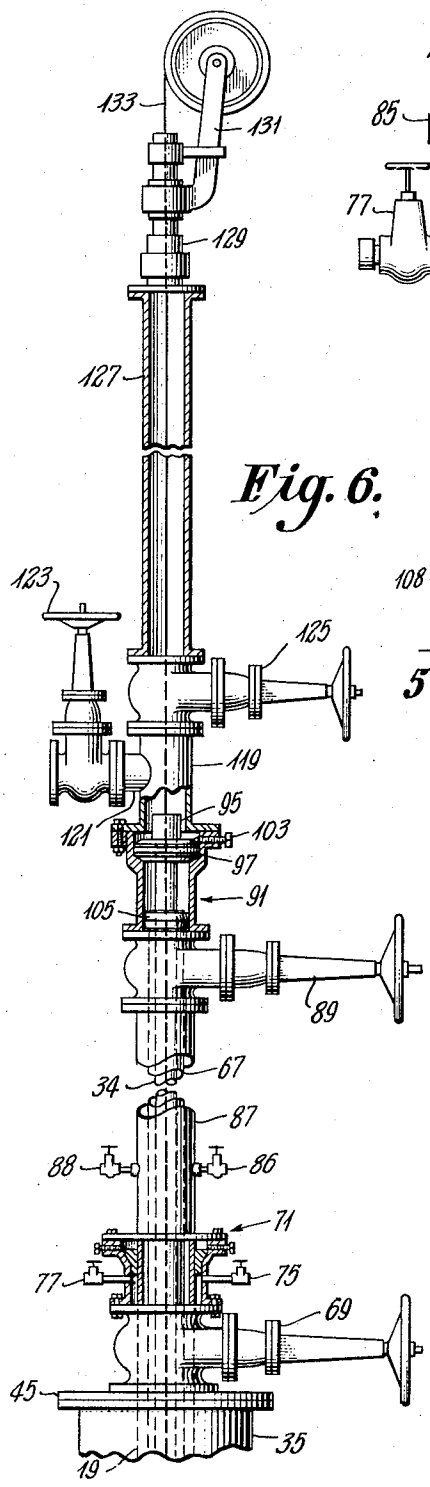


Fig. 6.

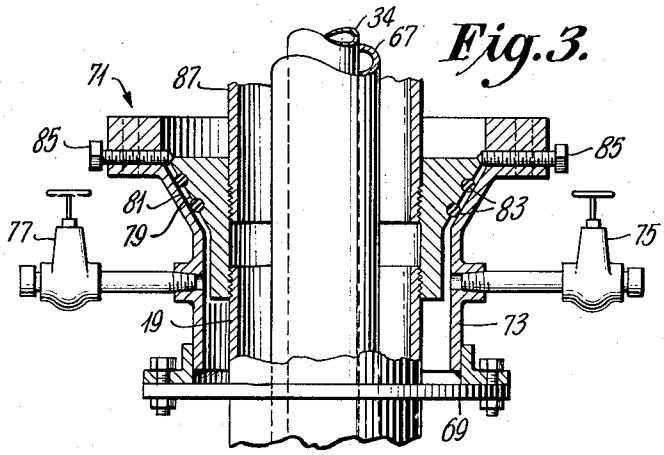


Fig. 3.

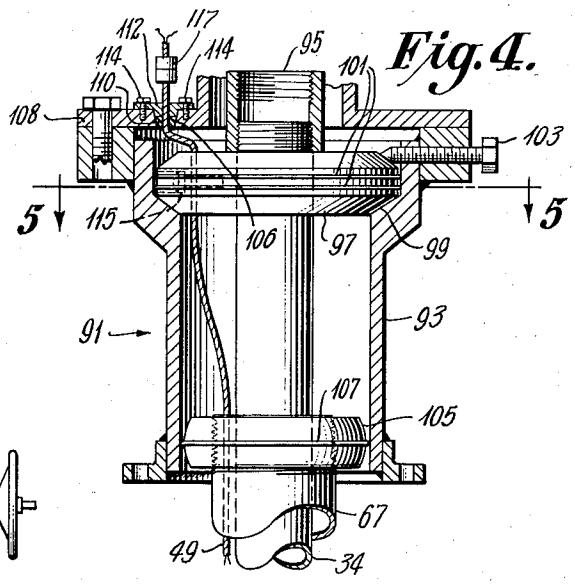


Fig. 4.

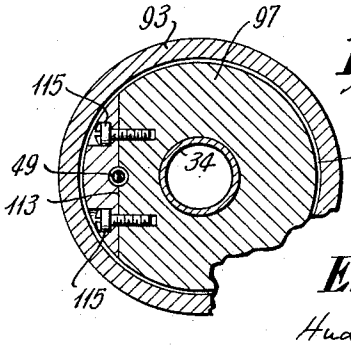


Fig. 5.

INVENTOR.
E. S. Miles
Hudson & Young
ATTORNEYS

April 28, 1959 E. S. MILES 2,883,833

UNDERGROUND STORAGE SYSTEM AND METHOD OF OPERATING

Filed Jan. 22, 1954 3 Sheets-Sheet 3

Fig 8.

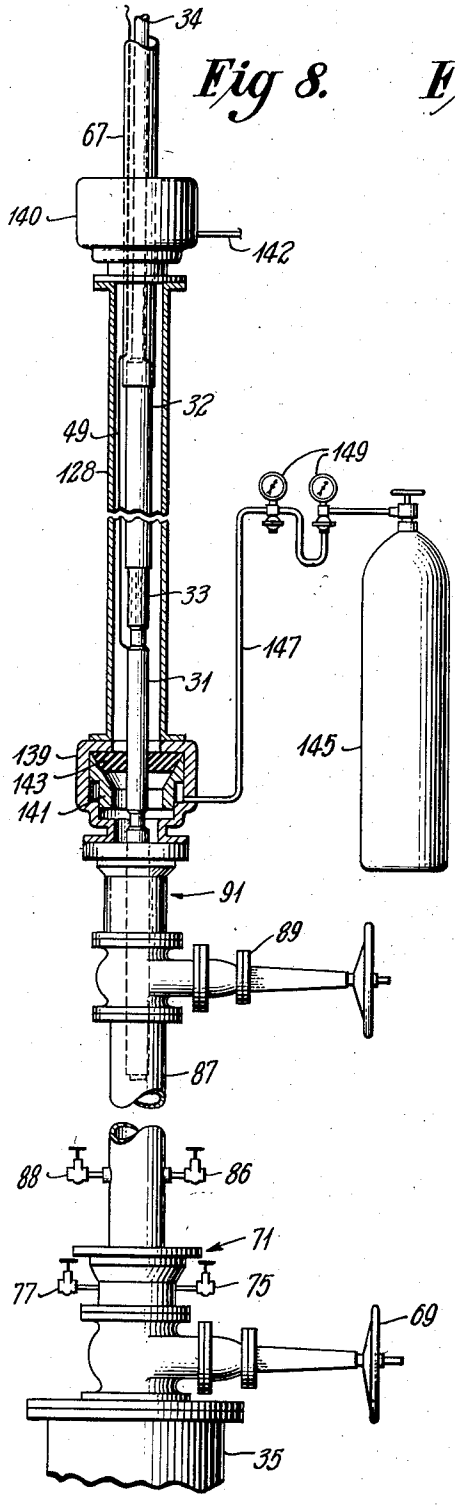
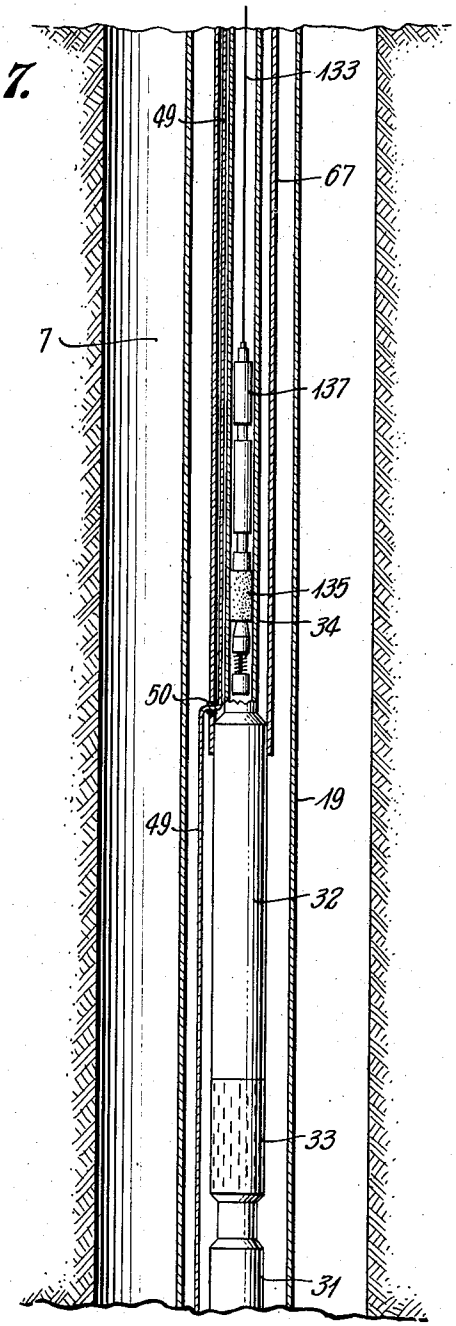


Fig. 7.



INVENTOR.
E. S. Miles
BY
Hudson & Young
ATTORNEYS

United States Patent Office 2,883,833 Patented Apr. 28, 1959

2,883,833

UNDERGROUND STORAGE SYSTEM AND METHOD OF OPERATING

Elburt S. Miles, Oklahoma City, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware

Application January 22, 1954, Serial No. 405,637

15 Claims. (Cl. 61—.5)

This invention relates to an underground storage system and to a method of operating an underground storage system. 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 an improved apparatus and method for inserting or withdrawing a submerged motor pump from an underground storage cavern.

Constantly expanding production of liquefied petroleum gas has created a definite problem in providing suitable storage facilities for this material. Due to the high vapor 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 of the stored material in a safe manner. The problem becomes extremely acute where it is necessary to store large quantities of such materials during the off-season. In addition to the expenses involved, the use of steel tanks is limited by shortages in production.

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 a copending application, Serial No. 348,344, filed April 13, 1953, by Edwin E. Reed, entitled, "Pressurized Storage Stystem and Method of Operating" there is disclosed an underground storage stystem for liquefied petroleum gas which is capable of storing extremely large quantities of this material at a very small unit cost. The storage system therein and the storage system and method of operating herein is not limited to the 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 containers.

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 outside of the container. It is recognized that such pumps will have to be pulled from the container from time to time for repair or replacement. To do this, some means must be provided to prevent the loss of large quantities of vapor from

the container. There is disclosed in Serial No. 348,344 a system and method to insure that the container can be tightly sealed during the time the pump is being operated or being inserted or withdrawn.

In particular, there is disclosed in Serial No. 384,344 a spring-operated, normally-closed valve at the bottom of the casing, the valve stem of which is displaced by the pump body and thereby the valve is opened, when the pump is lowered into operating position. Accordingly, when the pump body is raised, the valve closes thereby sealing the storage container. In the event that the valve should fail to close properly when the pump body is raised, however, other means are required to seal the container while inserting or withdrawing the pump. One of such means, well-known in oil well drilling operation, is the use of blowout preventers to seal the space between the casing and the discharge tubing from the pump while the pump and associated parts are inserted or withdrawn, the discharge tubing itself being plugged by any of many well-known means. However, in the case where the pump being used is of the submersible motor type, the electrical cable from the submersible motor-pump unit runs from the motor between the casing and the pump discharge tubing to the source of electrical power at the surface. The presence of the electrical cable on the outside of the motor-pump unit and the pump discharge tubing makes it very difficult to effectively prevent the escape of the stored product through the space between the pump and its discharge tubing and the casing by the use of ordinary blowout preventers.

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

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

A still further object of this invention is to provide an improved apparatus and method for introducing and withdrawing a submersible motor-pump unit from a pressurized container without loss of vapors from high pressure products stored therein.

A still further object is to provide an improved apparatus and method for using ordinary blowout preventers when introducing or withdrawing a submersible motor pump unit from an underground storage system for liquefied petroleum gas.

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, partially in elevation, of an underground storage system constructed in accordance with this invention;

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

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

Figure 4 is an enlarged sectional view, partially in elevation, of a tubing head and slip joint for suspending therefrom a submersible motor-pump unit activated by an electrical cable extending from the surface to the motor unit;

Figure 5 is a sectional view taken along the line 5—5 of Figure 4 looking in the direction of the arrows;

Figure 6 is an enlarged vertical sectional view, partially in elevation, of the apparatus at the top of the shaft including a lubricator, wire line stuffing box and swivel pulley;

Figure 7 is a vertical sectional view, partially in elevation, of a portion of the shaft showing a retrievable plug installed in the pump discharge tubing; and

Figure 8 is a vertical sectional view, partially in elevation, of the apparatus at the top of the shaft including a lubricator and blowout preventers, showing the motor-pump unit partially removed from the shaft.

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.

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. 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 1 communicates by means of tunnels 3 and 5 with an enlarged vertical shaft 7 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 3 is a drain pipe or header 9, and the headers of all the caverns extend through the respective tunnels and communicate with the shaft 7. Each storage cavern is provided with a drain pipe 11 which at its lower end is connected to the header 9 and which extends upwardly into the associated storage chamber 1. Thus, should the tunnel 3 become choked with rock due, for example, to caving, the main storage portion of the chamber still communicates with the shaft through its associated pipe 11 and header 9. 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 5, each upper tunnel being connected to one of the storage chambers 1 and communicating with shaft 7. Disposed in each tunnel 5 are a pair of vent pipes 13 and 15 communicating with shaft 7 and the adjacent chamber 1. 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 5 can be eliminated and the described communication between the upper portion of the storage chambers and the shaft can be effected solely by the vent pipes 13 and 15. Conversely, the vent pipes 13 and 15 could be eliminated and venting effected through the tunnel. Where different types of caverns are used any suitable means can be used 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 17 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 7 incorporates pump mechanisms 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 17, or such filling means or pipe can extend to the bottom of the cavern. Material withdrawn from storage flows through the lower tunnel 3 and/or header 9 to the shaft 7 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.

Casing 19 extends from the surface of the earth through means hereinafter described and the lower portion of shaft 7 into a well 21 formed at the bottom of the shaft. It will be noted that the well 21 is below the level of the tunnels 3 and caverns so that fluid can flow from each of the caverns into the well. In the well the casing 19 is received within a section of pipe 23 which is anchored in a mass 25 of cement in the well. Disposed at the lower end of the casing 19 is a valve 27 and immediately above the valve 27 is a pumping unit comprising a submersible electrical motor 29, actuated by a suitable electrical current source at the surface, a protector or seal 31, a pump 32 and pump intake 33, the pumping unit being actuatable to lift the fluid stored within the system through the shaft to the surface. Pump 32 is supported within casing 19 by means of pump discharge tubing 34. Other conventional submersible motor-pump units, for example, with the motor above the pump, can be used.

A tubular metal liner 35 formed, for example, from steel is provided at the top of the shaft and this liner is anchored by a mass 37 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 5 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 39 adjacent the surface of the earth and supporting and anchoring the liner 35, a generally cylindrical portion 41 surrounding the body of the liner 35, and a lower inwardly protruding portion 43 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 35, well head 45 and mass 37 of cement constitute collectively means for sealing the shaft 7 at a region above the level of the lower tunnels 3 and upper tunnels 5. It will also be evident that liner 35, well head 45 and tunnels 3 and 5 constitute collectively a conduit extending through a boundary of the cavern and closably communicating therewith. A manhole closed by a cover 47 is provided in the liner 35 for access into a storage system for any desired purpose.

Referring now to Figure 2, there is shown an enlarged view of the lower portion of shaft 7, and in particular, there is shown an enlarged and detailed view of valve 27 and the motor-pump unit with an electrical cable 49 for supplying electrical current to motor 29. Cable 49 is not shown in Figure 1 in order to clarify other elements in Figure 1. It will be noted that fluid passes into pipe 23 from tunnels 3 and headers 9 leading to storage chambers. From the bottom of pipe 23 fluid enters a lower section 51, Figure 2, of valve 27, this valve section being centered by a series of vanes 53 protruding from the wall of the pipe 23. The valve 27 further includes a valve head 55 engageable with a valve seat 57 in an upper section 59 of the valve. The valve head is mounted upon a stem 61 which passes through a spider 63 and cooperates with a spring 65 urging the valve towards closed position. When the pump is positioned as shown in Figures 1 and 2, the valve stem 61 is displaced downwardly by the pump body and the valve is open, as shown, thereby allowing fluid to pass through the valve to the pump intake 33 in the casing. When the pump is raised to a position above the valve, not

shown, the valve is closed by the action of spring 65 and no fluid can enter the casing from the lower section 51 of the valve.

In accordance with the invention, the electrical cable 49, which extends to a source of electrical current at the surface, and pump discharge tubing 34 are encased within a safety pipe 67 threaded or otherwise attached securely to the top of pump 32, as shown in Figure 2. Cable 49 extends from motor 29, outside protector 31, pump inlet 33 and pump 32, through a sealing means 50, such as a stuffing box, in the wall of safety pipe 67 immediately above pump 32, into the space between safety pipe 67 and tubing 34 and to said current source at the surface.

Referring again to Figure 1, it will be noted that the discharge tubing 34, safety pipe 67 and casing 19 all extend upwardly through shaft 7, the liner 35 and the well head 45 to the surface, where these parts all pass through a valve 69 on top of the well head. Immediately above valve 69 is a casing head 71 from which the casing 19 is hung. Referring to Figure 3, it will be noted that the casing head 71 includes a generally cylindrical body 73 bolted to an adjacent flange of valve 69 and provided with valved connections 75 and 77. The upper end of casing 19 is threaded to a tapered annular block 79 which engages a complementary tapered surface 81 of the body 73, the block 79 being provided with a plurality of sealing gaskets 83 and held in position by bolts 85. The gaskets 83 seal the region between the body 73 and casing 19, this region communicating through valve 69 with the top portion of shaft 7. A pipe 87 is threaded to the top of block 79, this pipe extending upwardly to and supporting a valve 89, Figure 1. The discharge tubing 34 and safety pipe 67 extend through pipe 87 and valve 89 to a combination tubing head and slip joint 91, the detailed construction of which is shown by Figure 4. Valved pipes 86 and 88 provide access to the space between pipe 87 and safety pipe 67.

Referring to Figure 4, it will be noted that the tubing head 91 includes a generally cylindrical body 93, the lower end of which rests upon and is supported by an adjacent flange of valve 89. The upper end of tubing 34 is threaded or otherwise securely attached to a collar 95 which rests upon a tapered annular block 97 which engages a complementary tapered surface 99 of the body 93, this block being provided with a plurality of annular sealing gaskets 101. If desired, a seal can be provided between tubing 34 or collar 95 and block 97. This can be accomplished, for example, by providing collar 95 with a tapered lower surface (not shown) which fits into a complementary tapered ground seal (not shown) in block 97, or by providing sealing means between tubing 34 and the inner cylindrical bore of block 97 by means of one or more O rings (not shown). Such a seal may be desirable in some instances to prevent the stored product entering the space between body 93 or safety pipe 67 and tubing 34. However, such a seal is not usually necessary since the above mentioned space can be vented at the same time tubing 34 is vented, as described hereinbelow. A plurality of hold-down lugs 103 retain block 97 in position on the tapered surface 99 of block 93. A seal is maintained between body 93 and safety pipe 67 by an annular member 105, which is securely attached to the upper end of safety pipe 67, and a gasket 107. To provide for the passage of the electrical cable 49 through block 97, said block is split along the line 113, Figure 5, and cable 49 is held tightly in place by screws 115. Cable 49 leaves tubing head 91 through the hole 106 in flange 108. A seal is maintained around cable 49 by means of a gasket 110, held in place by means of plate 112 and screws 114. A socket connection 117 in cable 49 above tubing head 91 facilitates removal of electrical cable 49 therefrom.

Referring again to Figure 1, a T-section 119 rests upon and is supported by an adjacent flange of tubing head 91. An arm 121 of T-section 119 provides a suitable outlet for the stored fluid, and arm 121 is controlled by valve 123 attached thereto. Valve 125 rests upon the other arm of T 119 and is attached to the flange thereof.

In assembling and operating the apparatus described thusfar, valve 69 is opened and the casing 19 is hung from casing head 71 so that it extends downwardly through valve 69 to its position within pipe 23, Figure 1. Attached to the lower end of the casing is the valve 27 which is normally closed so that, once the casing is inserted and the casing head sealed, no material can pass through the casing to the surface nor between the casing and the body 73. Pipe 87, having valved pipes 86 and 88 connected thereto, is installed by threading pipe 87 into the threaded tapered annular block 79, and valve 89 is installed upon the flanged upper end of pipe 87. In the initial operation of the system, the storage system can be filled with the fluid to be stored at this point, or the following steps of inserting the submersible motor pump and associated parts can be carried out, thereafter filling the system. Valve 89 is opened and the motor-pump unit, suspended from the discharge tubing 34 and having safety pipe 67 attached to the top of the pump 32 and about tubing 34, is lowered into the casing, section by section. When the motor-pump unit is suspended a short distance above the valve 27, the annular member 105, Figure 4, and sealing gasket 107 are attached to the upper end of safety pipe 67 and positioned in the upper end of the cylindrical body 93, Figure 4. Tapered annular block 97 and sealing gaskets 101 are positioned about discharge tubing 34 and a short distance above the complementary tapered surface 99 of body 93. Collar 95 is attached to tubing 34. At this time, in the event the cavern already contains the fluid to be stored, the interior of the casing is pressurized as by connecting valves 75 and 86, Figure 3. It will be noted in Figures 1, 3 and 6 that valved connections 75 and 77 communicate with the space between casing 19 and shaft liner 35 and it will be noted in Figures 1, 6 and 8 that valved pipes 86 and 88 provide access to the interior of casing 19, i.e., the interior of pipe 87 which is an extension of casing 19. By connecting valved connection 75 or 77 to valved pipe 86 or 88, respectively, by conduits not shown, a means is provided for equalizing the pressure in the underground storage system with the interior of casing 19. Thereupon, the tubing 34 is lowered to its final position, thereby causing the motor body 29 to engage the valve 27 and open it. When the foregoing steps are followed with fluid in the system, annular member 105 and sealing gasket 107 prevent the escape of vapor in the casing during the period when the tubing, motor-pump unit and safety pipe are being lowered into final operating position. The tubing 34, motor-pump unit, and safety pipe 67 are supported by collar 95 resting upon block 97. The electrical cable 49 is threaded through the split sections of block 97 as it is positioned as described above. Upon energizing motor 29, pump 32 lifts fluid through the tubing 34, the surface structure 69, 89, 91, Figure 1, to and out T-section 121.

In the event it is necessary to remove the motor-pump unit for servicing, a procedure is set forth in Serial No. 348,344, referred to above, based on the closure of valve 27 when tubing 34 is lifted to remove the motor body 29 from engagement with valve stem 61. However, as was previously pointed out, valve 27 can fail to close for many reasons, for example, a piece of rock or other foreign material can become lodged therein, and when a submerged motor pump is used, the presence of the electrical cable outside the pump and discharge tubing makes extremely difficult the use of blowout preventers for sealing the region between the discharge tubing and the casing, this region communicating openly with the pressure of the stored liquid if valve 27 should fail to close. In accordance with my invention the discharge tubing and the electrical cable are encased within a safety pipe attached to the top of the pump and the safety pipe positioned within the casing.

Referring to Figures 6, 7 and 8, there are shown ap-

paratus elements and a method for withdrawing and/or inserting the motor-pump unit when the safety pipe is installed in accordance with my invention and the downhole valve 27 has failed to close.

Referring particularly to Figures 6 and 7, there is shown a means for closing the discharge tubing 34. A lubricator 127 is installed upon the upper flange of valve 125. A wire line stuffing box 129 and a swivel pulley 131 are mounted upon the upper end of lubricator 127. A wire line 133 is attached to pulley 131 and attached to the end of wire line 133 is a retrievable plug 135 and a setting tool 137.

In utilizing these elements to close tubing 34, the lubricator 127 is first installed as shown and described. The plug 135 and setting tool 137 are attached to line 133 and lowered into lubricator 127. The wire line stuffing box 129 and swivel pulley 131 are then installed above the lubricator. Valve 125 is opened and plug 135 and setting tool 137 are lowered to a position within tubing 34 just above pump 32 and set in place. Valve 123 is opened to bleed off stored material from discharge tubing 34. Lubricator 127 and associated parts thereabove are removed. Thereafter, T-section 119, valve 123 and valve 125 are removed.

It will be noted that tubing 34 is sealed by plug 135, the space between safety pipe 67 and casing 19 is sealed by annular member 105 and gasket 107, and the space between casing 19 and liner 35 is sealed by annular block 79 and gaskets 83.

Referring now to Figure 8, there is shown means for sealing the space betwen safety pipe 67 and casing 19 while tubing 34 is raised, thereby raising the motor-pump unit and safety pipe 67. A blowout preventer 139 is installed upon the upper flange of tubing head 91. Lubricator 128 is installed upon blowout preventer 139 and another blowout preventer 140 is installed upon the upper end of lubricator 128. Blowout preventers 139 and 140 must be of sufficient size so that, when they are open, annular block 97 and annular member 105 can pass through them. Blowout preventers 139 and 140 can be any of the conventional types used in well drilling operations, and it is to be understood that the term "blowout preventer" as used in the appended claims is intended to include all devices capable of forming a sliding seal about a pipe which can be opened or closed at will. One effective type of blowout preventer comprises a contractor piston 141 which is actuated by fluid pressure to contract or constrict a packing unit 143 of flexible material, for example, molded rubber. Fluid pressure applied to the blowout preventers can be supplied by a bottle 145 of compressed gas, such as nitrogen or carbon dioxide or any other source of fluid pressure, such as an air compressor. The fluid pressure in bottle 145 is supplied to blowout preventer 139 through a conduit 147 having suitable pressure gauges 149. It is understood of course that a similar source of fluid pressure is supplied to blowout preventer 140 through conduit 142.

To withdraw tubing 34 and associated parts, using the elements shown in Figure 8, a length of lifting pipe (not shown) is threaded into collar 95 thereby furnishing a means for lifting tubing 34. Blowout preventer 140 is closed about the lifting pipe and blowout preventer 139 is opened, initially. Hold down lugs 103, Figure 4, are loosened and tubing 34 is raised until anular block 97, annular member 105 and a portion of safety pipe 67 is within lubricator 128; blowout preventer 139 is then closed about safety pipe 67 and blowout preventer 140 is opened. Thus, blowout preventer 140 seals the contents of the system when the seal between safety pipe 67 and casing 19 is broken by raising safety pipe 67 out of tubing head 91. Tubing 34 is then raised, stripping safety pipe 67 through blowout preventer 139 and thereby maintaining a seal on the contents of the system, until the point at which safety pipe 67 is attached to pump 32 is just below blowout preventer 139, i.e., specifically until sealing means 50 and the top of pump 32 are just below blowout preventer 139. Blowout preventer 140 is then closed about safety pipe 67 and blowout preventer 139 is opened. Tubing 34 is then further raised until the submersible pump unit is within lubricator 128, i.e., specifically until sealing means 50 and the top of pump 32 are just below blowout preventer 140. It is to be noted that lubricator 127 must be of sufficient length to contain the submersible motor pump, i.e., specifically, of sufficient length so that, when sealing means 50 is immediately below blowout preventer 140, the lower end of motor 29 is above valve 89 which is thereupon closed, sealing the contents of the system. Blowout preventer 140 is then opened and th motor-pump unit is withdrawn for such service and/or replacement as is required. Obviously, tubing 34, safety pipe 67 and the motor-pump unit can be inserted into the casing by the reverse manipulation of blowout preventers 139 and 140, using lubricator 128.

If valve 27 is to be repaired and/or replaced a plug can be placed in the lower end of the casing through the use of a lubricator similar to the one used to set a plug in the tubing and all apparatus elements above casing head 71 are removed and a first blowout preventer, lubricator and a second blowout preventer installed thereupon in that order. A length of lifting pipe, not shown, is threaded into block 79, see Figure 3, thus furnishing a means for raising casing 19. The second blowout preventer is closed about the lifting pipe and the first blowout preventer opened. Casing 19 with block 79 attached thereto is raised until block 79 is through the first blowout preventer and within the lubricator. The first blowout preventer is then closed about casing 19, the second blowout preventer is opened and casing 19 raised until valve 27 is above valve 69, which is then closed, sealing the contents of the system. The first blowout preventer is then opened and the remainder of casing 19 with valve 27 attached thereto is removed.

As an added feature of my invention I provide a means for preventing the loss of even a small amount of vapors from the product stored in the underground storage system while the aforedescribed operation is carried out. A non-inflammable, inert gas, such as helium or nitrogen is introduced to the space betwen safety pipe 67 and the casing 19 through valve pipes 86 and 88. The pressure of the inert gas is maintained approximately equal to the vapor pressure of the stored product and any leakage past the blowout preventers during the withdrawal or insertion of the motor-pump unit as described herein will be the inert gas. This method of preventing the escape of vapor is also applicable to the removal and insertion of casing 19, the inert gas being admitted in this case through valves 75 and 77.

While the 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. A method according to claim 15, wherein loss of pressure from the pressurized container is further prevented by the steps comprising, admitting an inert, non-inflammable gas to said conduit prior to withdrawing said pump from said conduit and maintaining the pressure of said gas approximately equal to the pressure in said container throughout the steps recited in claim 15.

2. In a method of inserting into and withdrawing from a pressurized container and without loss of pressure therein a submersible motor pump and discharge tubing attached thereto, said container being provided with a conduit extending through a boundary of said container and closably communicating therewith and within which are positioned said submersible motor pump and discharge tubing, said submersible motor pump being actuatable by a source of power applied through a power cable attached to the motor of said submersible

motor pump, said cable extending from said motor to said source of power externally to said discharge tubing, the steps comprising, positioning a plug in said discharge tubing, attaching a safety pipe encasing said discharge tubing and said cable to said submersible motor pump, forming a first slidable seal in said conduit above said boundary, positioning above said first seal a lubricator pipe of sufficient cross-sectional size to contain said safety pipe and of sufficient length to contain said submersible motor pump, positioning above said lubricator pipe a second slidable seal, passing said pump and the adjacent portion of said safety pipe into said lubricator pipe, closing said second seal about said safety pipe and opening said first seal, inserting said submersible motor pump, with safety pipe attached thereto and containing said cable and plugged discharge tubing, into said conduit until the point at which said safety pipe is attached to said submersible motor pump is below said first seal, closing said first seal about said safety pipe and opening said second seal, further inserting said submersible motor pump into said conduit to its operating position, removing said plug from discharge tubing, repositioning said plug in said discharge tubing, and withdrawing said submersible motor pump until the point at which said safety pipe is attached to said submersible motor pump is immediately below said first seal, closing said second seal and opening said first seal, further withdrawing said pump until said pump is within said lubricator pipe, closing said conduit, opening said second seal and completely withdrawing said pump.

3. In a method for inserting a submersible motor pump into a pressurized container, said container being provided with a conduit extending through a boundary of said container and closably communicating therewith, said submersible motor pump having a discharge tubing attached thereto and being actuatable by a source of power applied through a power cable attached to the motor of said submersible motor pump, said cable extending from said motor to said source of power externally to said discharge tubing, the steps comprising, positioning a plug in said discharge tubing, attaching a safety pipe encasing said discharge tubing and said cable to said submersible motor pump, forming a first slidable seal in said conduit above said boundary, positioning above said first seal a lubricator pipe of sufficient cross-sectional size to contain said safety pipe and of sufficient length to contain said submersible motor pump, positioning a second slidable seal above said lubricator pipe, passing said pump and the adjacent portion of said safety pipe into said lubricator pipe, closing said second seal about said safety pipe and opening said first seal, inserting said submersible motor pump, with safety pipe attached thereto and containing said cable and plugged discharge tubing, into said conduit until the point at which the safety pipe is attached to said submersible motor pump is below said first seal, closing said first seal about said safety pipe and opening said second seal, further inserting said submersible motor pump into said conduit to its operating position, and removing said plug from said discharge tubing.

4. In a method for inserting a submersible motor pump having discharge tubing attached thereto into an underground storage system containing a fluid under pressure without loss of pressure therein, said underground storage system comprising a plurality of intercommunicating caverns and a conduit extending through a boundary of said caverns and closably communicating therewith, said submersible motor pump being actuatable by a source of power at the surface of the ground and applied through an electrical cable positioned externally and adjacent to said discharge tubing and attached to the motor of said submersible motor pump, the steps comprising, positioning a plug in said discharge tubing, encasing said discharge tubing and said cable within a safety pipe and attaching said safety pipe to said submersible motor pump,

forming a first slidable seal in said conduit above said boundary, positioning above said first seal a lubricator pipe of sufficient cross-sectional size to contain said safety pipe and of sufficient length to contain said submersible motor pump, positioning a second slidable seal above said lubricator pipe, passing said pump and the adjacent portion of said safety pipe into said lubricator pipe, closing said second seal about said safety pipe and opening said first seal, inserting said submersible motor pump, with safety pipe attached thereto and containing said cable and plugged discharge tubing, into said conduit until the point at which the safety pipe is attached to said submersible motor pump is below said first seal, closing said first seal about said safety pipe and opening said second seal, further inserting said submersible motor pump into said conduit with appropriate opening and closing of said seals to place said pump in operating position, and removing said plug from said discharge tubing.

5. A method according to claim 4, wherein loss of pressure from the underground storage system is further prevented by the steps comprising, admitting an inert, non-inflammable gas to said conduit prior to inserting said submersible motor pump into said conduit and maintaining the pressure of said gas approximately equal to the pressure of said fluid in said underground storage system throughout the steps recited in claim 4.

6. In a pressurized storage system, in combination, a closed container for holding a fluid under pressure, a length of outer tubing passing through an upper wall of said container and extending into the bottom region thereof, a first head positioned above said container supporting said outer tubing, means sealing said container at the point of entry of said outer tubing, a length of inner tubing disposed in spaced relationship to and within said outer tubing, a second head positioned above said first head supporting said inner tubing, a submersible motor pump supported by said inner tubing and disposed within the outer tubing in the bottom of the container, a source of power for actuating said submersible motor pump, a power cable extending from said source of power to said submersible motor pump, said cable extending from said source of power, through said first and second heads and the space between the inner and outer tubings to said submersible motor pump, means for introducing the fluid to be stored into said system, and a safety pipe disposed in spaced relationship to and concentrically within the outer tubing and about said cable and the inner tubing, said safety pipe being rigidly attached to and supported by said submersible motor pump and extending through said first head to said second head, and means sealing the space between the outer tubing and the safety pipe.

7. In an underground storage system, in combination, an underground storage cavern, an enlarged vertical shaft extending from the surface of the earth to a region adjacent said cavern, a tunnel connecting said shaft with the bottom region of said cavern, means sealing the cavern above the level of said tunnel, a tubular casing disposed in the shaft and extending through said sealing means, a discharge tubing disposed within said casing and extending from the surface to the lower portion of said casing, an electrically-powered submersible motor pump disposed within said casing at the level of the bottom region of the cavern attached to and suspended by said discharge tubing, a source of electrical power at the surface of the earth, an electrical power cable attached to said submersible motor pump and extending therefrom externally to said discharge tubing to said source of power, a safety pipe disposed about said discharge tubing and power cable, attached to and supported by said pump, means for introducing fluid to be stored into said cavern, said source of power actuating said pump so as to withdraw fluid from the bottom of said shaft and pump said fluid to the surface.

8. In an underground storage system, in combination,

an underground storage cavern, an enlarged vertical shaft extending from the surface of the earth to a region adjacent said cavern, a lower tunnel connecting said shaft with the bottom region of said cavern, an upper tunnel connecting said shaft with the upper region of said cavern, sealing means including a well head for sealing said shaft above the level of the upper tunnel, a casing disposed in the shaft and extending from the surface of the earth through the sealing means to a region below the level of the lower tunnel, a discharge tubing disposed within said casing and extending from the surface to the lower portion of said casing, an electrically powered, submersible motor pump attached to and suspended by said discharge tubing and disposed within said casing adjacent the bottom region of said casing, a source of electrical power at the surface of the earth for furnishing power to actuate said pump, an electrical power cable extending from said source of power to said submersible motor pump, said cable passing through said sealing means, through said casing and adjacent the outside of said discharge tubing, a safety pipe disposed about said cable and said discharge tubing and attached to and supported by said pump, and means for introducing fluid to be stored into said cavern.

9. In an underground storage system, in combination, an underground storage cavern, an enlarged vertical shaft extending from the surface of the earth to a level below the bottom region of said cavern, a tunnel connecting said shaft with the bottom region of the cavern, whereby a well is formed in said shaft below the level of said tunnel, a tubular liner at the top of said shaft, a mass of cement anchoring said liner in position in the earth, a well head closing the top of said tubular liner, a tubular casing extending from the surface through the well head and said shaft into said well, a valve surrounding said casing and positioned on the well head, a casing head mounted on top of said valve and supporting said casing, tubing disposed concentrically within and spaced from said casing, an electrically powered, submersible motor pump supported by said tubing at the bottom of said casing, a source of electrical power at the surface of the earth for actuating said pump, an electrical power cable extending from said source of power through the space between the tubing and the casing to said submersible motor pump, a safety pipe disposed concentrically within and in spaced relationship to said casing and about said cable and tubing, said safety pipe being attached to and supported by said submersible motor pump, a second valve mounted above said casing head surrounding said safety pipe, a tubing head disposed above said second valve, supporting said tubing and comprising sealing means for sealing the space between said safety pipe and said casing, means connecting the top portion of the tubing to a discharge line, and means for introducing fluid to be stored into said cavern.

10. In a method of inserting a submersible motor pump having discharge tubing attached thereto into an underground storage cavern containing a fluid under pressure without loss of pressure therein, said submersible motor pump being actuatable by a source of electric power at the surface of the ground and applied through an electrical power cable positioned externally to said discharge tubing and attached to the motor of said submersible motor pump, said underground storage cavern being provided with a conduit extending through a boundary of said cavern and closably communicating therewith, the steps comprising, positioning a plug in said discharge tubing, encasing said discharge tubing and said cable within a safety pipe and attaching said safety pipe to said submersible motor pump, forming a plurality of spaced, slidable seals in the upper portion of said conduit, passing said pump and said safety pipe through said seals, and inserting said pump into said conduit to its operating position, said insertion being accompanied by appropriate opening and closing of said seals to prevent loss of pressure from said cavern.

11. In a method of withdrawing a submersible motor pump having discharge tubing attached thereto from an underground storage cavern containing a fluid under pressure without loss of pressure therein, said submersible motor pump being actuatable by a source of electric power at the surface of the ground and applied through an electric power cable positioned externally to said discharge tubing and attached to the motor of said submersible motor pump, said underground storage cavern being provided with a conduit extending through a boundary of said cavern and closably communicating therewith, and within which are positioned said submersible motor pump and discharge tubing, the steps comprising, positioning a plug in said discharge tubing, providing a safety pipe encasing said discharge tubing and said cable and attached to said submersible motor pump, forming a plurality of spaced, slidable seals in the upper portion of said conduit, passing said safety pipe from said conduit through said slidable seals, and withdrawing said safety pipe and pump from said conduit with appropriate opening and closing of said seals to prevent loss of pressure from said cavern.

12. A method according to claim 11, wherein loss of pressure from the underground storage cavern is further prevented by the steps comprising admitting an inert, non-inflammable gas to said conduit prior to withdrawing said pump from said conduit and maintaining the pressure of said gas approximately equal to the pressure of said fluid in said cavern throughout the step of withdrawing said pump from said conduit.

13. In a method for withdrawing a submersible motor pump having discharge tubing attached thereto from an underground storage system containing a fluid under pressure without loss of pressure therein, said underground storage system comprising a plurality of intercommunicating caverns and a conduit extending through a boundary of said caverns and closably communicating therewith, and within which are positioned said submersible motor pump and discharge tubing, said submersible motor pump being actuatable by a source of power at the surface of the ground and applied through an electrical cable positioned externally and adjacent to said discharge tubing and attached to the motor of said submersible motor pump, the steps comprising positioning a plug in said discharge tubing, providing a safety pipe encasing said discharge tubing and said cable and attached to said submersible motor pump, forming a first slidable seal in said conduit above said boundary, positioning above said first seal a lubricator pipe of sufficient cross sectional size to contain said safety pipe and of sufficient length to contain said submersible motor pump, positioning a second slidable seal above said lubricator pipe, passing the upper portion of said safety pipe through said first seal into said lubricator pipe, closing said first seal about said safety pipe and opening said second seal, passing said safety pipe through said second seal and withdrawing said submersible motor pump with safety pipe attached thereto and containing said cable and plugged discharge tubing from said conduit with appropriate opening and closing of said seals to prevent loss of pressure from said storage system.

14. In a pressurized storage system, in combination, a closed container for holding fluid under pressure, a length of outer tubing passing through a wall of said container, and extending into the bottom region of said container, means sealing said container at the point of entry of said outer tubing, a length of inner tubing disposed in spaced relationship to and within said outer tubing, a submersible motor pump attached to said inner tubing and disposed within said outer tubing in said bottom region of said container, a source of power outside said container and tubings, a power cable extending from said source of power to said pump passing in-

side said outer tubing but outside said inner tubing, a safety pipe within said outer tubing positioned adjacent said pump and enclosing said inner tubing and said cable, and means for sealing the space between said outer tubing and said safety pipe.

15. In a method of withdrawing a submersible motor pump having discharge tubing attached thereto from a pressurized container without loss of pressure therefrom, said container being provided with a conduit extending through a boundary of said container and closably communicating therewith, said submersible motor pump being actuable by a source of electric power applied through a power cable attached to the motor of said pump, positioned externally to said discharge tubing but within said conduit and extending from said power source outside said container to said pump within said container, the steps comprising, positioning a plug in said discharge

tubing, providing a safety pipe forming a zone closed to said container enclosing said cable and discharge tubing, forming a plurality of spaced slidable seals in said conduit, passing said safety pipe from said conduit through said slidable seals, and withdrawing said safety pipe and pump from said conduit with appropriate opening and closing of said seals to prevent loss of pressure from said container.

References Cited in the file of this patent

UNITED STATES PATENTS

2,148,327	Smith et al.	Feb. 21, 1939
2,221,798	Hollander	Nov. 19, 1940
2,230,830	Coberly	Feb. 4, 1941
2,545,175	Stump et al.	Mar. 13, 1951
2,604,049	Martin	July 22, 1952