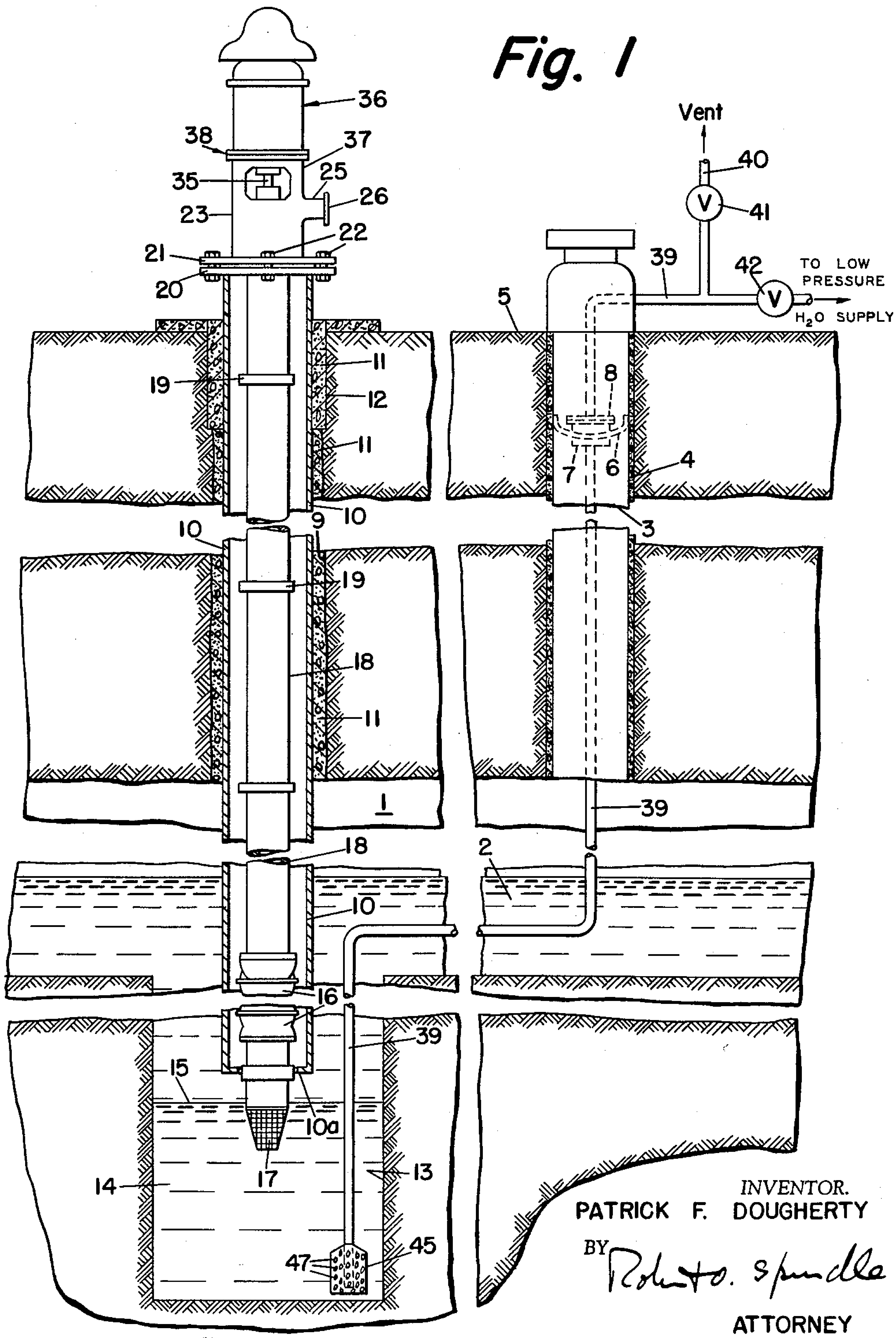
UNDERGROUND STORAGE OF FLUIDS

Filed July 20, 1960 3 Sheets-Sheet 1

Fig. 1



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April 9, 1963 P. F. DOUGHERTY 3,084,515

UNDERGROUND STORAGE OF FLUIDS

Filed July 20, 1960 3 Sheets-Sheet 2

Fig. 2

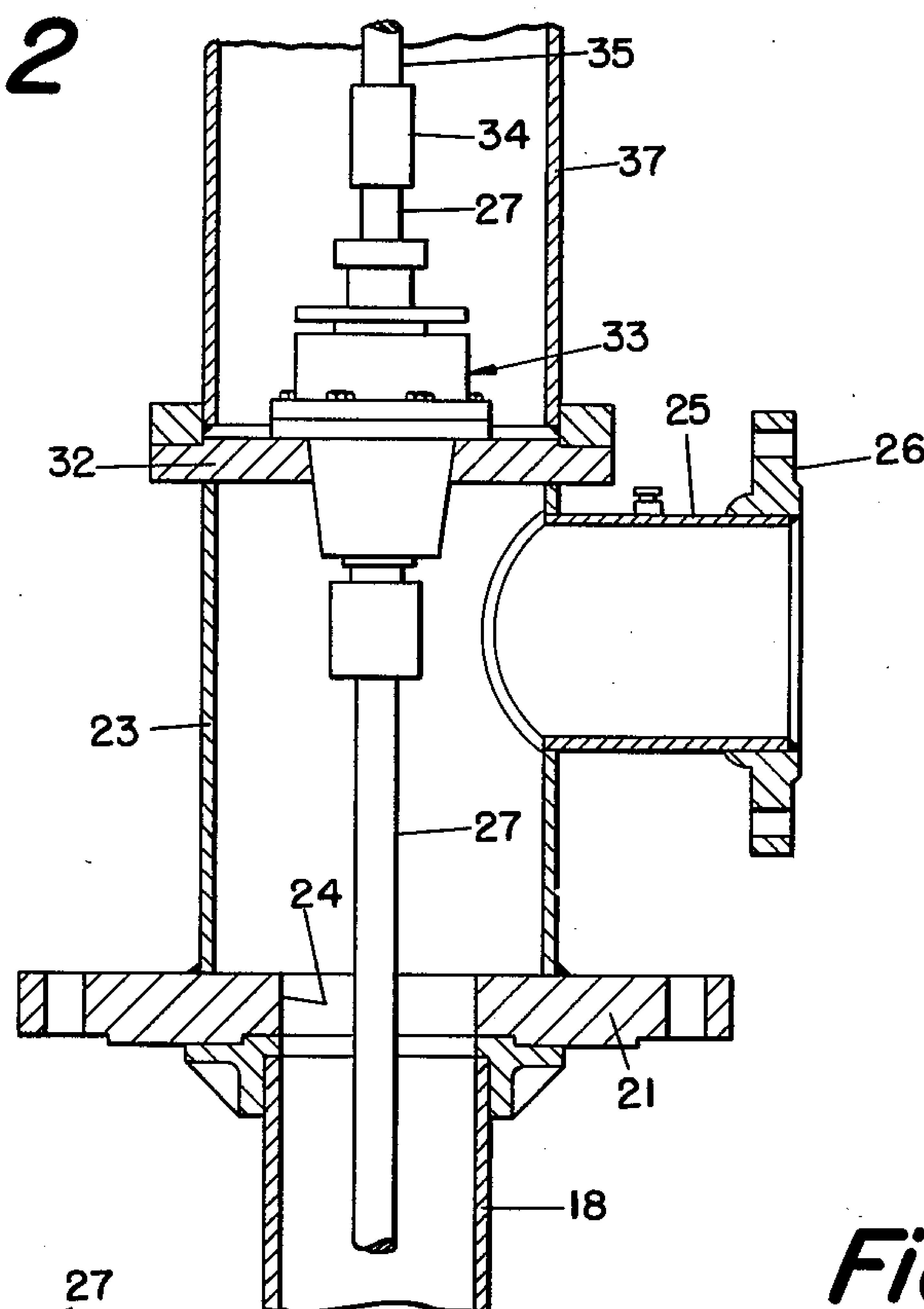


Fig. 3

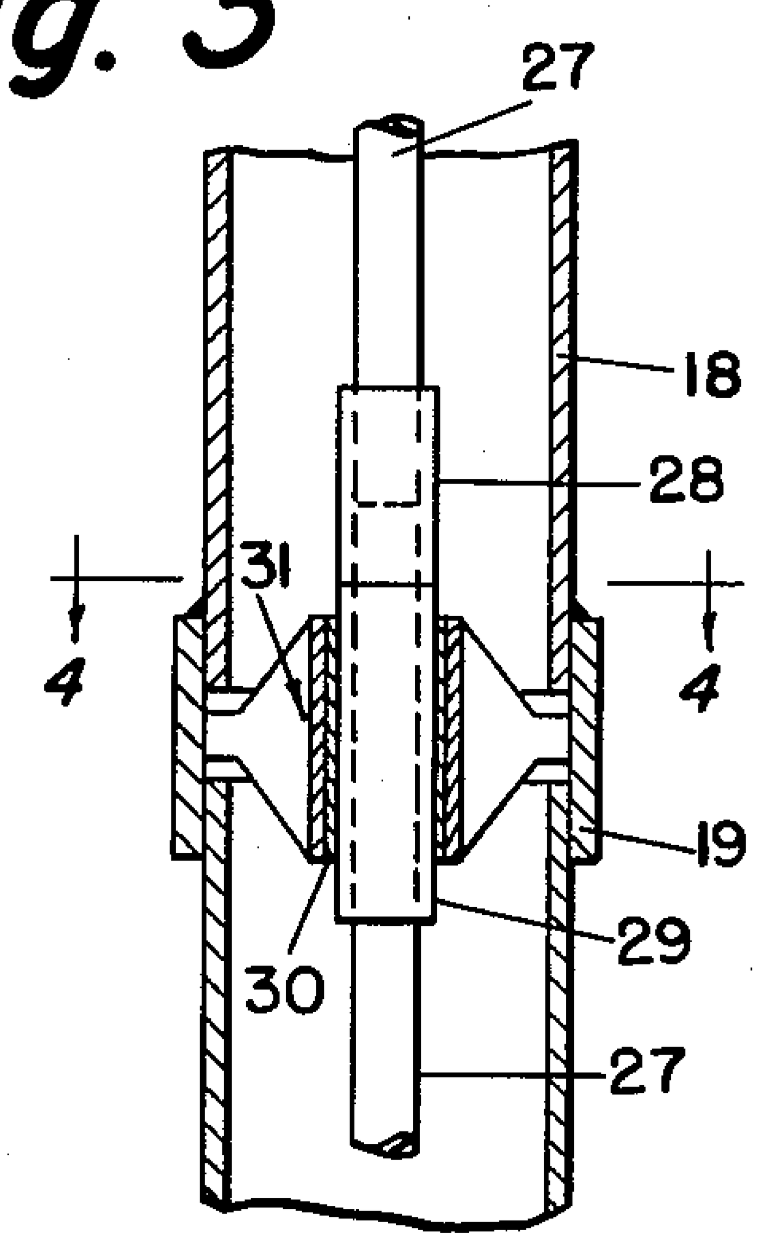
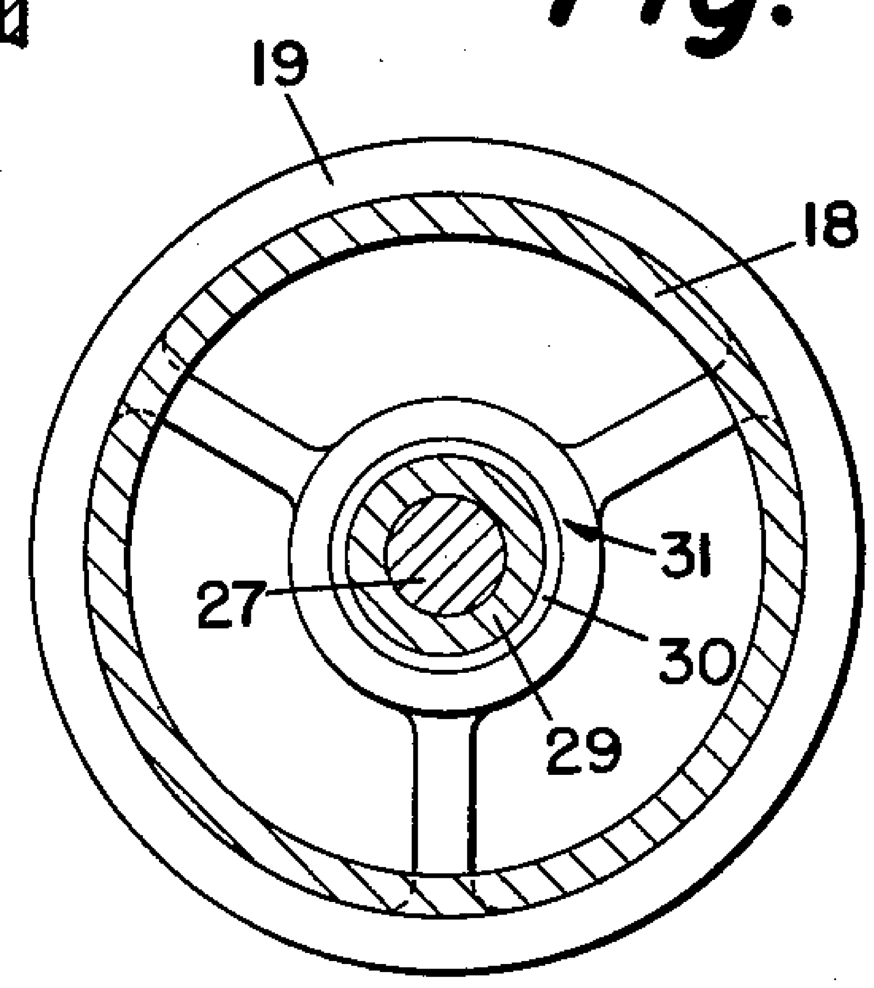


Fig. 4



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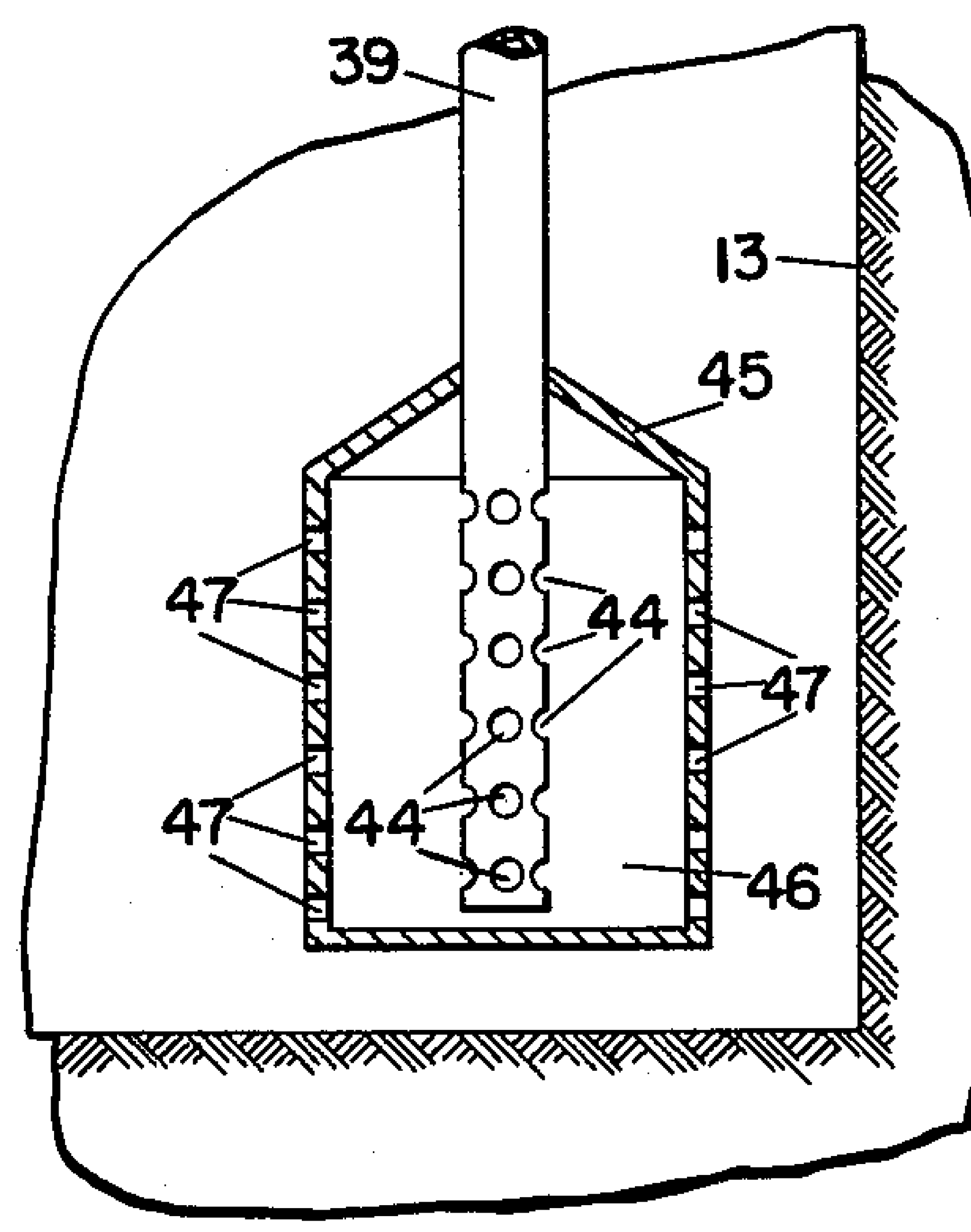
Filed July 20, 1960 3 Sheets-Sheet 3

Fig. 5



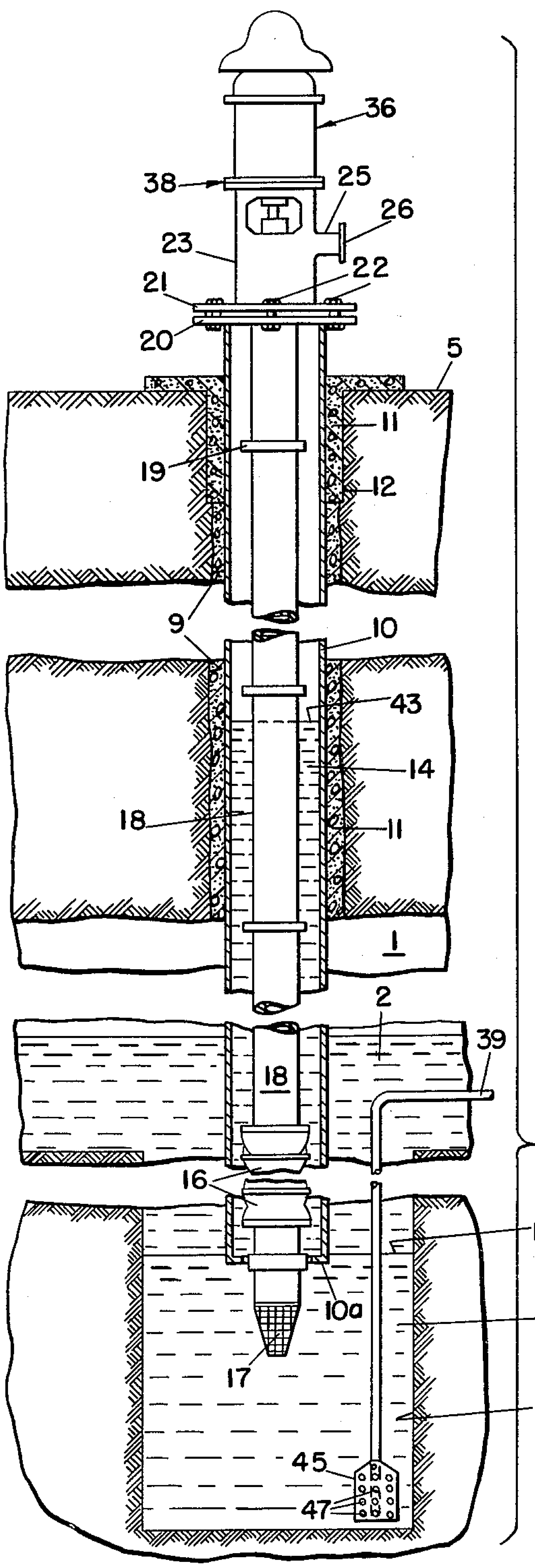


Fig. 6

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1

3,084,515
UNDERGROUND STORAGE OF FLUIDS

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Filed July 20, 1960, Ser. No. 44,158
4 Claims. (Cl. 61—.5)

This invention relates to the subterranean storage of fluids under pressure.

Fluid products may be stored under pressure in a subterranean cavern mined or prepared in a rock (e.g., granite) formation. For purposes of illustration, such a cavern may be used for the storage under superatmospheric pressure of propane, in a liquid state, and such will be referred to further hereinafter. However, it is pointed out that caverns of this type can be used for the storage of other highly volatile and combustible liquefied hydrocarbons, such as butane, or the material known as "casinghead gasoline." Also, such a cavern can be used for the storage of various other fluids (either liquids or gases), whether or not they are hydrocarbons.

In such mined subterranean caverns, there are normally small fissures in the rock through which water continuously seeps into the cavern, apparently from the surface of the ground. One or more sumps (a typical cavern may include two sumps) are provided in the floor of the rock cavern, for collection of this water. A large-diameter casing (twelve inches in diameter, for example) extends from the surface of the earth vertically down into the sump, and a smaller pipe (eight inches in diameter, for example) is positioned concentrically within this casing, this smaller pipe also extending from the surface vertically down into the sump. A pump, for example of the multistage turbine type, is secured to the lower end of the smaller pipe and is positioned within the sump, this pump being powered by means of a vertical rotatable shaft mounted in the eight-inch pipe and mechanically connecting the pump to an electric motor at the surface. The electric motor may be mounted on the upper end of the eight-inch pipe, and the assembly of motor, shaft, eight-inch pipe, and pump is secured only to the upper end of the outer twelve-inch casing, so as to hang freely therein. The pump intake strainer may be located about twenty inches beneath the bottom open end of the outer casing, which location is of course within the sump. With two such sumps in the cavern, there would be two outer casings, two smaller pipes concentric with the respective outer casings, and two respective pumps with their corresponding motors and shafts. The two sumps referred to are within the cavern proper, and are displaced sideways or laterally from the main large-diameter shaft used for mining or excavating the cavern.

The two pumps referred to are used for pumping the stored fluid out of the cavern when desired; these transfer or discharge pumps abstract fluid from their respective sumps and discharge the same through their respective eight-inch discharge pipes to the surface. Since water is heavier than the stored fluid product (e.g., hydrocarbon) and is immiscible therewith, each pump will of course first pump out any water which may be present in the respective sump, above the pump intake, and will thereafter pump the stored fluid product out of the cavern, by way of the sump and the eight-inch pipe. Although the primary function of the pumps is to transfer or discharge stored product from the cavern, such pumps can also be used whenever desired to pump excess water out of the sumps or cavern. Thus, whenever water rises in the sumps above the pump intakes, the pumps can be started and the water pumped to the surface by way of the eight-inch pipes.

A mechanical seal or packing arrangement is provided

2

at the top of the eight-inch pipe, above the fluid discharge coupling at the upper end of this pipe, for sealing the upper or motor end of the rotatable pump shaft into this pipe, thereby to keep the hydrocarbon fluid out of the motor; in this connection, it will be recalled that the water (and stored fluid) are pumped to the surface through the eight-inch pipe, and are discharged therefrom by way of a coupling located above the surface. At times, a leakage problem may occur at this mechanical seal, necessitating that the same be repaired. Also, it may be desirable to occasionally pull the pump out (by means of the eight-inch pipe) for repairs. For repair of the mechanical seal, the upper end of the eight-inch pipe must perforce be opened to the atmosphere, while in order to pull the pump, the upper end of the outer casing and also the upper end of the inner pipe must necessarily be opened to the atmosphere. The fluid (e.g., liquefied hydrocarbon) is stored under superatmospheric pressure (e.g., about 150 pounds per square inch, absolute) in the cavern, to keep the hydrocarbon in a liquid state. To avoid undesirable leakage of the stored hydrocarbon from the cavern when the eight-inch pipe and/or the outer casing are opened, it is necessary to provide a water column within the casing (assuming that the casing is opened, which is usually the case) and also within the eight-inch pipe, sufficiently high to counterbalance (by its hydrostatic head) the pressure in the storage cavern.

According to prior practice, this water column would be created by pumping water into the casing-pipe annulus (and also into the eight-inch pipe) at the top of the casing. However, this requires an excessive pump pressure (necessarily provided by a very large and costly pump) in order to overcome the pressure in the vapor space in the annulus; this latter pressure may be in excess of the pressure in the cavern.

An object of this invention is to provide, in a subterranean storage cavern having a discharge pump, an improved arrangement for providing a water sealing column in the pump discharge pipe. The arrangement of this invention is greatly simplified as compared to prior arrangements, in that no special high pressure pump is needed to bring about this result, the low pressure of a public utility water system being more than sufficient for the purpose. Therefore, the inventive arrangement is quite inexpensive.

The objects of this invention are accomplished, briefly, in the following manner. A small-diameter fluid (water) pipe or line is run from ground level down into the lower part of each respective sump, the lower open end of this pipe or line being located several feet below the respective pump intake; thus, the line extends below the permanent water level in the sump, and the lower end thereof is always immersed in water. Whenever repairs are to be made, water is pumped at low pressure into the upper end of this small line, filling it up and causing water to flow (largely as a result of the weight of the column of water above or in excess of a column of water which would counterbalance the pressure in the cavern) into the sump until it rises above the bottom open end of the casing. This seals off the casing-pipe annulus (and also the interior of the inner pipe, since the water is concurrently rising through the pump intake and pump), and continued input of water through the small line (while the upper ends of the casing and eight-inch pipe are slowly being vented to atmosphere) causes water to rise in the annulus, and also in the eight-inch pipe, to a height such as to counterbalance the pressure in the cavern. This counterbalancing water column can then function to prevent leakage of the stored pressured fluid from the cavern, so that the necessary repairs (e.g., the pulling out of the pump) may be safely carried out.

A detailed description of the invention follows, taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic or overall representation of a preferred subterranean cavern arrangement according to this invention;

FIG. 2 is a fragmentary vertical (longitudinal) cross-section showing the construction at the upper end of the pump operating shaft, the same having been removed from the outer casing;

FIG. 3 is a fragmentary vertical (longitudinal) cross-section showing the construction at one of the joints in the inner pipe, the same having been removed from the outer casing;

FIG. 4 is a transverse cross-section taken along line 4—4 of FIG. 3, drawn on an enlarged scale and illustrating one of the bearings for the pump operating shaft;

FIG. 5 is a view of a portion of the sump of FIG. 1 drawn on an enlarged scale, certain parts being shown in cross-section; and

FIG. 6 is a fragmentary view similar to FIG. 1, but illustrating the casing partially filled with water to provide a counterbalancing water column.

Referring first to FIG. 1, which is a somewhat schematic representation of a completed cavern arrangement according to this invention, a subterranean mined cavern **1** (mined, e.g., in a rock formation such as granite) can serve as a storage container for a fluid product **2** under pressure. For purposes of illustration, the cavern will be described as being utilized for the storage under pressure of propane, in a liquid state. However, it is pointed out that it can be used for the storage of other highly volatile and combustible liquefied hydrocarbons, such as butane, or the material known as "casinghead gasoline." Also, it can be used for the storage of various other fluids (either liquids or gases), whether or not they are hydrocarbons. The fluid **2** (e.g., propane) is stored under superatmospheric pressure in the cavern **1**, to allow storage of this material in its liquid state. By way of example, propane may be stored in such a cavern at a pressure on the order of 150 pounds per square inch, absolute.

As described in the copending application, Serial No. 17,602, filed March 25, 1960, the cavern may be filled or supplied with fluid by way of a casing **3**, through which a fill pipe (not shown) passes. The casing **3** (of forty-two inches I.D., for example) is cemented at **4** into the large-diameter main or working shaft or bore of the cavern, and this casing extends from the surface **5** down to the top or roof of the cavern **1**. The casing **3**, by way of example, may be about 380 feet long, while the height of the cavern itself, from floor to roof, may be about forty feet. The fill pipe referred to extends down into a sump (not shown) which is provided in the floor of cavern **1**, beneath the lower end of casing **3**.

The upper end of casing **3** is capped or sealed by means of a pressure vessel whose bottom dished head or closure is illustrated at **6**. Sealed into the bottom closure **6** is a manway **7** which has a removable manhead **8**.

All of the detailed structure so far described is set forth in more detail in said copending application, and forms no part of the present invention. Therefore, it need not be described further herein.

The cavern **1** has substantial horizontal dimensions, that is, it has a rather large horizontal cross-sectional area. By way of example, for a cavern of 250,000 barrels (10,500,000 gallons) volume capacity, the horizontal diameter of the cavern would be about 211 feet, assuming a cavern height of forty feet and a right cylindrical configuration for the cavern. Off to the side or laterally from the main bore and casing **3**, there are located two smaller-diameter shafts or bores, one of which is illustrated at **9**. These bores are located in respective opposite directions from the main bore and casing. Since the construction and arrangement of these two smaller bores are substantially identical, only one will be described in detail. These two smaller bores are used for ventilation during mining or preparation of the underground cavern, and thereafter (during utilization of the subterranean cavern for product storage) are used in connection with the transfer or discharge equipment, as will be described. After the cavern construction is completed, the casing **10** (of twelve inches I.D., for example) is run into the shaft **9** and is cemented therein, as indicated at **11**. The casing **10** extends a substantial distance below the roof of cavern **1**, as will be described in more detail hereinafter, and is cemented all the way from the surface **5** down to the cavern roof. For purposes of additional strength and rigidity, it is desirable to utilize, at the upper end of bore **9** but around the exterior of casing **10**, a concrete-filled pipe **12** which is twenty inches in O.D. and approximately fifty feet long.

It is desired to be pointed out, at this juncture, that in FIG. 1 the diameter of bore **9** hase been greatly exaggerated, to show detail. Actually, of course, this diameter is much smaller than that of casing **3**, as will be realized from the numerical values previously set forth.

A sump **13** is provided in the floor of cavern **1**, this sump being located vertically below bore **9** and concentric therewith. By way of example, sump **13** may be cylindrical in configuration, with a depth of twenty-two feet below the floor of cavern **1** and with a diameter of 7½ feet. Casing **10** extends below the roof of the cavern **1**, entirely through the vertical dimension of the cavern and down into sump **13**. The lower open end of casing **10** may be flanged inwardly slightly, as at **10*a***. This lower end **10*a*** may be located about 12½ ft. below the cevern floor.

In mined subterranean caverns such as described herein, water continuously seeps into the cavern through small fissures in the rock, apparently from the surface of the ground. This water is heavier than the fluid product **2** being stored in cavern **1** and is immiscible therewith, so finds its way into sump **13**, where it collects as a water layer **14**. The water-product interface is denoted by numeral **15** in FIG. 1.

In order to transfer or discharge fluid product from cavern **1**, as well as to occasionally pump out the water which collects in sump **13**, a pump **16** is utilized. This pump has its intake **17** (covered by a strainer screen) extending into sump **13**, below the lower end **10*a*** of casing **10**. The lower end **10*a*** of casing **10** may be termed the "point of submergence" of the pump. By way of example, the lower end of the intake **17** may be located about eight feet above the bottom of sump **13**, and about twenty inches below the "point of submergence" **10*a***. The pump **16** may be of the deep-well, submersible, multistage turbine type, and the bottom of the lowermost turbine stage may be located about five inches above the "point of submergence" **10*a***.

Pump **16** is secured to the lower end of a pipe **18** (eight inches in diameter, for example) which is positioned concentrically within casing **10**. The discharge connection of pump **16** is coupled to the lower end of pipe **18**, so that this pump, when operating, discharges the fluid pumped thereby into the interior of pipe **18**. Pump **16** abstracts fluid from sump **13**, by way of pump intake **17**. Pipe **18** is made up of sections adjacent ones of which are joined together by means of suitable couplings **19**. Casing **10** is provided with a mounting flange **20** at its upper end (above surface **5**), and to the upper end of pipe **18** is secured a matching flange **21** (see FIG. 2). It can be seen that pipe **18** extends from a point above the surface **5** down to the upper end of pump **16**, which end is preferably located below the floor of cavern **1** in sump **13** (although in FIG. 1, due to drawing space limitations, the upper end of the pump is illustrated as being above the cavern floor). Bolts **22**, passing through flanges **20** and **21**, are used to mount the upper end of pipe **18** in casing **10**, some form of packing being used here to close off from the atmosphere the upper end of casing **10**, and more particularly the upper end of the casing-pipe annulus.

By reason of the above-described construction, which fastens only the upper end of pipe **18** to the upper end of casing **10**, pipe **18** with its appendant pump **16** hangs freely in the casing **10**. Therefore, after uncoupling the flanges **20** and **21** (and after effecting certain other important operations, to be described hereinafter), the pipe **18** and attached pump **16** may be withdrawn as a unit, up through fixed casing **10**. Flange **10***a* at the lower end of casing **10** is dimensioned to provide sufficient clearance to permit this upward withdrawal.

A hollow cylindrical discharge head **23** (see FIG. 2) is sealed to the upper face of mounting flange **21**, this head being concentric with pipe **18**. The interior of head **23** is placed in fluid communication with the interior of pipe **18** by means of an aperture **24** in flange **21**. A discharge coupling **25**, having the same diameter as pipe **18**, is sealed through the cylindrical wall of head **23** and is provided with a flange **26** at its outer end for connection to a suitbale discharge pipe (not shown). The pump **16**, when suitably mechanically driven as described hereinafter, takes fluid in from sump **13** and pumps it up through pipe **18** to the surface, discharging it out through items **24**, **23**, and **25**. It may be seen, therefore, that the pump **16** discharges through the eight-inch pipe **18**.

In order to drive the pump **16** from the surface, a rotatable shaft **27** is utilized. This shaft is mounted and supported for rotation in pipe **18**, concentrically thereof, and extends from the surface down to the pump **16**. Shaft **27** is driven by a motor at the surface, in a manner to be described hereinafter, and in turn mechanically drives the pump **16** at the bottom of pipe **18**. At locations adjacent to each of the pipe couplings **19**, shaft couplings **28** join together adjacent sections of the shaft **27** (see FIG. 3). At each of the pipe couplings **19** (which may for example be ten feet apart, along the length of pipe **18**), bearing means are provided for supporting and journaling for rotation the shaft **27**. Immediately below each of the shaft couplings **28**, a sleeve **29** is mounted on shaft **27**, this sleeve being of stainless steel, for example. This sleeve can rotate in an annular bearing member **30** which is made of suitable bearing material and is held in position by a spider member **31** (see FIG. 4) which is in turn held between two adjacent sections of pipe **18**. A suitable thrust bearing is utilized at the bottom end of shaft **27**, where the latter is attached to the operating shaft of pump **16**. The spaces between the arms of the spider-like arrangement **31** allow the fluid being pumped upwardly through pipe **18** to pass by the various shaft bearings.

At the upper end of discharge head **23**, above coupling **25**, a closure member **32** is provided for sealing off the upper end of pipe **18** from the atmosphere. This closure member sealingly engages the upper end of hollow head **23**, and a mechanical seal arrangement, denoted generally by numeral **33**, is utilized to seal the rotatable pump shaft **27** through the closure **32**, thereby to complete the seal at the upper end of pipe **18**. Details of the mechanical seal arrangement need not be given, since it forms no part of the present invention. Above the mechanical seal **33**, a coupling member **34** connects the extreme upper end of shaft **27** to a shaft **35** which is the output shaft of an electric motor **36** (see FIG. 1). A hollow spacer member **37** is secured to the upper side of closure **32** and extends between such closure and the motor proper. Spacer member **37** surrounds the upper side of seal **33**, as well as items **34** and **35** (see FIG. 2).

A separable coupling, indicated generally by numeral **38**, is used to fasten motor **36** to member **37**. When it is desired to repair or inspect seal **33**, this coupling may be separated to obtain access to such seal. The seal **33** may also be separable, to facilitate operations when it is desired to pull pump **16** out for repairs or maintenance. When the latter becomes necessary, motor **36** is uncoupled and seal **33** is separated. Then, flanges **20** and **21** are uncoupled as aforementioned. Following this, pipe **18**, shaft **27**, and pump **16** may all be withdrawn at a unit, up through the fixed casing **10**. The joints or couplings **19** and **28**, in the pipe **18** and shaft **27** respectively, allow convenient removal and handling, at the surface, of these very long items.

As previously mentioned, two similar transfer or discharge equipments are utilized in connection with the cavern. It will therefore be understood that, for the cavern, items **9** through **13** and **16** through **38** are provided in duplicate.

In FIG. 1, the water level **15** in the sump **13** is illustrated as being above the pump intake **17**. Whenever water rises in the sump above such intake, the pump **16** can be started (by energization of the electric motor **36**) and the water pumped out through the discharge coupling **25** at the top of pipe **18**. Also (and the function to now be described is really the primary function of the pump **16**), pump **16** can be started to pump or transfer stored fluid product out of the cavern, when desired. The pump **16** will first pump out any water which may be present in sump **13** above the level of pump intake **17**, and will thereafter pump the stored fluid product out of cavern **1**, by way of sump **13** and pipe **18**.

It will be appreciated that there is a permanent layer of water in the sump **13**, the top of this layer being located just at the bottom of intake **17**, since it is of course impossible for pump **16** to pump out any fluid below its intake. Anything extending down below the pump intake **17** will extend into this permanent water layer.

For repair of the mechanical seal **33**, the upper end of pipe **18** must necessarily be opened to the atmosphere, while in order to pull the pump **16** from the cavern, the upper end of casing **10** and also the upper end of pipe **18** must be opened to the atmosphere. To avoid undesirable leakage of product when the pipe **18** and/or the casing **10** are so opened, a water column must be provided within the casing **10**, and also within the pipe **18**, to counterbalance the pressure in the storage cavern. This invention provides a simple and inexpensive way of providing such water column.

Refer again to FIG. 1. A small water pipe or line **39** (e.g., two inches or three inches in diameter) is sealed through the cylindrical wall of the presure vessel closure on casing **3**, above the ground level **5**, this pipe then passing downwardly through this vessel. Pipe **39** is sealed through the bottom closure **6** and extends down through casing **3** into the cavern **1**, and thence proceeds laterally over to and down into sump **13**. Pipe **39** extends down into the lower part of sump **13**, to a point beneath the pump intake and thus down into the permanent water layer present in this sump. The lower end of pipe **39** may be located say two or three feet above the bottom of sump **13**, it being recalled that the pump intake **17** is located say seven or eight feet above the bottom of the sump.

Actually, two such pipes **39** are employed, one for each of the two sumps such as **13** which are provided in the cavern **1**, but since they are exactly alike in construction and function, only one will be illustrated and described. In a practical cavern, the various other pipes described in the aforementioned copending application may also pass downwardly, through the pressure vessel closure and casing **3**, into the cavern. To repeat herein the description of these other pipes would serve no useful purpose.

Alternatively, instead of running the pipe **39** down into the main casing **3**, it could be run down the bore **9** in which casing **10** is positioned, adjacent the outside of the casing. If this latter expedient were employed, pipe **39** would of course be run before casing **10** is cemented in position.

The lower end of pipe **39** is maintained in fluid communication with the permanent water layer in sump **13** by means of a series of perforations in the lower end of this pipe, as will be described hereinafter in connection with FIG. 5. At the upper end of pipe or line **39** a vent pipe 40 is provided; this latter pipe is coupled through a valve 41 to pipe 39. Also, the upper end of line 39 is coupled by way of a valve 42 to any low pressure water supply, such as a public utility water system.

Whenever repairs to pump 16 or to mechanical seal 33 are to be made, that is, when pipe 18 and/or casing 10 are to be opened, valve 41 is opened (valve 42 being closed at this time, as it normally is) to vent gas from the top of the line 39. This will cause water from the sump 13 to rise in pipe 39 until the water in this pipe reaches a level that counterbalances (by its hydrostatic head) the pressure in cavern 1. It will be recalled that the lower end of pipe 39 extends down into the permanent water layer in sump 13. Assuming a pressure in the cavern of 150 pounds per square inch absolute (equivalent to 135.3 pounds per square inch gauge), the level to which the water would rise in pipe 39 would be such as to give a hydrostatic head of about 295 feet. This height of water is considerably less than the 380 feet of vertical distance between the surface 5 and the roof of the cavern, not to mention the cavern height of 40 feet plus the vertical extent of pipe 39 within the sump 13.

As described, the lower end of pipe 39 extends down into the permanent water layer in sump 13, below pump intake 17. The volume of water always present in sump 13, between the lower end of pipe 39 and the lower end of pump intake 17, is such that there is sufficient water always available to rise in pipe 39 to the counterbalancing height (e.g., approximately 295 feet) as described, when vent valve 41 is opened. This precludes any possibility of combustible liquid issuing from vent 40, when valve 41 is opened to vent gas from the top of line 39.

When the water has reached the counterbalancing level in pipe 39, valve 42 is opened, to supply water at low pressure (e.g., from a public utility water system) to the line 39. Thus, in effect, water is pumped at low pressure into the line 39, to fill it up. Of course, to effect this filling up of line 39, some carefully controlled venting would need to take place at 40, 41, to vent the air from the top of pipe 39.

As pipe 39 begins to fill in this manner, the weight of the water above the counterbalancing water column causes water to flow down through line 39 into the sump 13. As it does so, the level of the water in the sump rises, since the effect is to supply water to the sump at a pressure in excess of the pressure in the cavern. By way of further explanation, the pressure in the cavern has already been balanced by a column of water in pipe 39, and water is being added to this pipe on top of the aforesaid counterbalancing column. Therefore, the flow down pipe 39 into sump 13 will easily take place, and the water supply to this pipe need be at only very low pressure. In fact, if ample time is available, instead of connecting the upper end of pipe 39 to a low pressure water supply, the equivalent action can be produced by merely opening the upper end of pipe 39 and manually pouring water thereinto, as by means of a funnel. Of course, in this latter case, venting would be automatic, and valve 41 could be closed.

As the supply of water to line 39 continues, in due course the level of water in the sump 13 rises above the bottom 10*a* of casing 10. This seals off the annulus between casing 10 and pipe 18. It will be realized that, as the water level in sump 13 rises, the water begins to rise also inside the pipe 18, since the pump intake 17 at the lower end of this latter pipe is open.

Once the casing-pipe annulus is sealed off as described, continued input of water through the small line 39 causes water to rise in the casing-pipe annulus (and also within the pipe 18). The water may be made to rise in the annulus and in pipe 18, rather than in the upper part of the sump and/or the cavern proper, by reducing the pressure at the upper end of the casing-pipe annulus, and at the upper end of pipe 18, to a value less than the pressure in the cavern. This reduction of pressure may be effected by venting to atmosphere the upper end of the annulus and the upper end of pipe 18, as by means of suitable vent valves and pipes (not shown). This venting must be done carefully, since if it is done too rapidly, pressured liquid product from the cavern may issue from the vent pipes.

Continued input of water through the line 39 causes water to rise in the annulus and also in pipe 18, and after a time it rises to a height that counterbalances (by its hydrostatic head) the pressure in the cavern. Under the conditions previously given by way of example, this would be about 295 feet. The situation just described is illustrated in FIG. 6, wherein the propane-water interface 15′ within the sump 13 has risen to a level just above the bottom 10*a* of the casing; the water 14 has risen in the casing-pipe annulus and in the pipe 18 to a level 43 which represents the top of the counterbalancing water column. Once this height has been reached, flow of product 2 out of the cavern 1 by way of the casing-pipe annulus or the pipe 18 is positively prevented. Then, the pipe 18 carrying the pump 16 can be pulled upwardly, out of the casing 10, along with the shaft 27. The water in the casing 10 prevents any leakage of fluid 2 (e.g., propane) from the cavern 1.

FIG. 5 is a detailed view, drawn on an enlarged scale, of the lower end of pipe 39. Adjacent its lower end, pipe 39 is provided with a plurality (here illustrated as six in number) of groups of perforations 44 which extend through the cylindrical wall of the pipe. Each group of perforations lies in a respective horizontal plane, and the several perforations comprising each group are spaced circumferentially around the pipe. To provide an extra margin of safety, in case some of the perforations 44 become clogged with dirt or other foreign matter, it is preferred that the total area of all the perforations 44 be at least twice the cross-sectional area of the pipe 39. A hollow cylindrical shell 45 (e.g., four or five inches in diameter) is sealed at its upper end to the lower end of pipe 39, to provide an annular chamber 46 around such pipe. Shell 45 is closed at its lower end, but is provided with a plurality (here illustrated as six in number) of groups of perforations 47 which extend through the cylindrical wall of the shell. Each group of perforations lies in a respective horizontal plane, and the several perforations comprising each group are spaced circumferentially around the shell. The perforations 47 in the outer shell 45 are staggered vertically with respect to the perforations 44 in the pipe 39.

It may be seen that perforations 44, chamber 46, and perforations 47 place the interior of water pipe 39 in fluid communication with sump 13. The staggering of perforations 47 with respect to perforations 44 provides a somewhat tortuous path for the water which flows down pipe 39 into sump 13, reducing the velocity of the flow and thus reducing the erosion by this water of the earthen wall of sump 13.

If desired, carbon dioxide may be added under pressure (e.g., ninety to one hundred pounds per square inch) to the water which is pumped into the line 39. The carbon dioxide would be soluble to a certain extent in the water, and would remain dissolved in the water until the latter rises in the casing-pipe annulus. There being essentially atmospheric pressure above the water in the annulus, the carbon dioxide would be released from the water in the annulus into the vapor space above the water level, due to the removal of pressure (it being recalled that the water is pumped at low pressure, but at a pressure above atmospheric, into line 39). The presence of carbon dioxide in the vapor, as the latter is vented from the casing-pipe annulus, would reduce the fire hazard.

The invention claimed is:

1. In a subterranean cavern for storing at superatmospheric pressure a fluid immiscible with water and of lower specific gravity than water, said cavern having a sump

extending downwardly from the floor thereof and communicating therewith: a pump for transferring fluid from said cavern to the surface, the intake for said pump being located in said sump; a casing surrounding but spaced from said pump, sealed into said cavern, and extending from said sump to the surface, the lower end of said casing being open; a quantity of water maintained permanently in said sump; and a water pipe extending from the surface of the earth vertically downwardly through a cavern seal and opening at its lower end into the water in said sump, the vertical length of said pipe being in excess of the length of the column of water necessary to counterbalance, by hydrostatic pressure, the effective pressure of the stored fluid, and said quantity of water being sufficient to fill said pipe to said column length, whereby water supplied to said pipe, above the top of said column, can flow down said pipe into said sump and thence upwardly into said casing to provide a pressure-counterbalancing water column therein.

2. An arrangement in accordance with claim 1, wherein said pump is mounted on the lower end of a fluid transfer pipe which extends from the discharge of said pump and through said casing to the surface.

3. An arrangement in accordance with claim 1, wherein the pump intake is located above the bottom of said sump and above the lower end of said water pipe.

4. An arrangement in accordance with claim 1, wherein said casing may be vented to the atmosphere to permit the flow of water from said sump upwardly into said casing.

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