Nov. 17, 1953

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2,659,209

UNDERGROUND LIQUID STORAGE FACILITY AND THE METHOD OF SELECTING AND PREPARING THE SAME

Filed March 23, 1951

3 Sheets-Sheet 1

FIG. 1

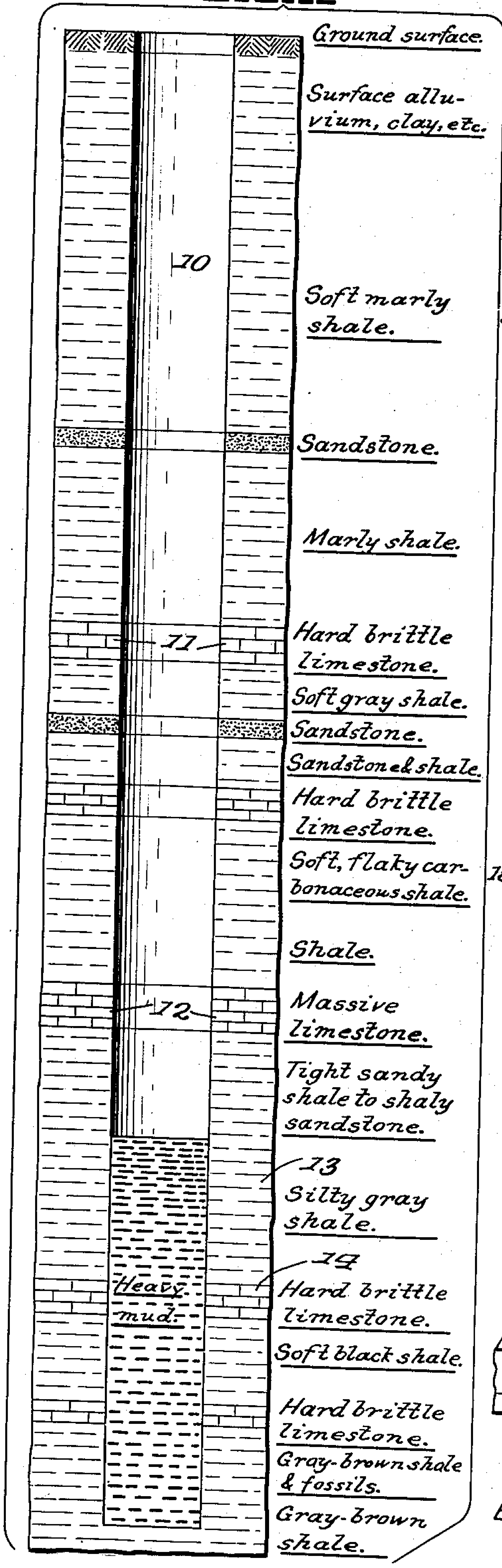


FIG. 2

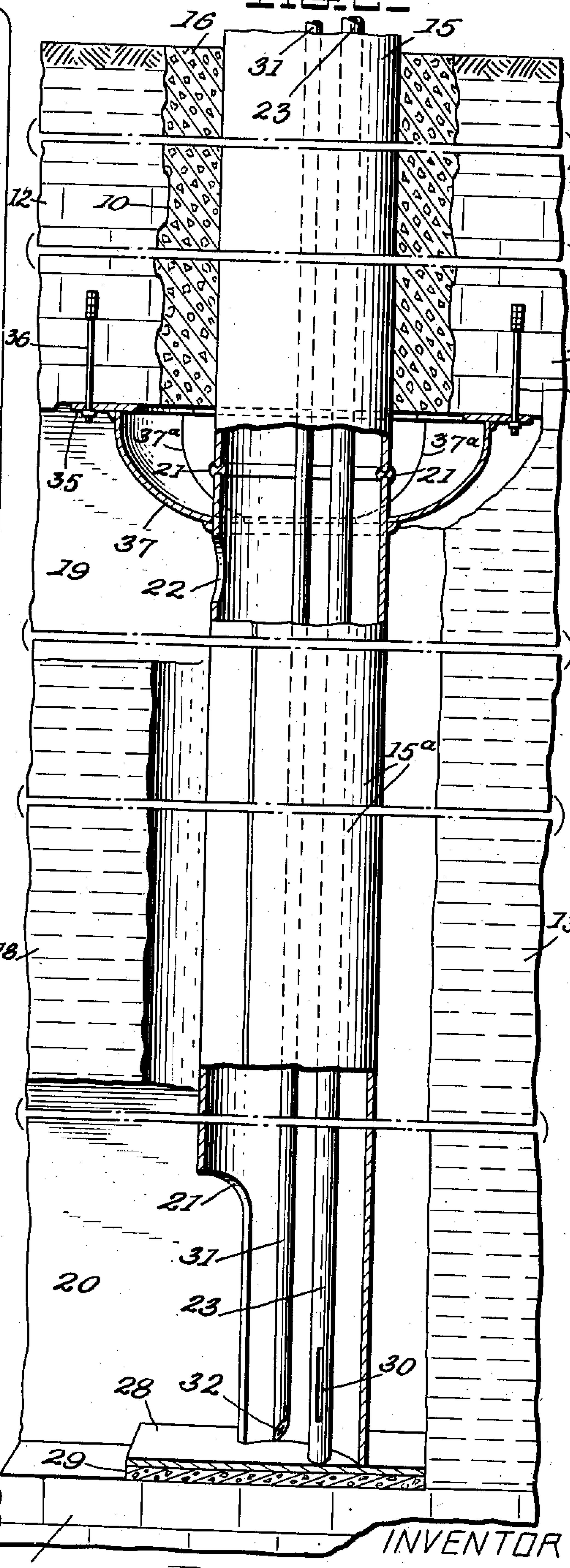


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FIG. 3

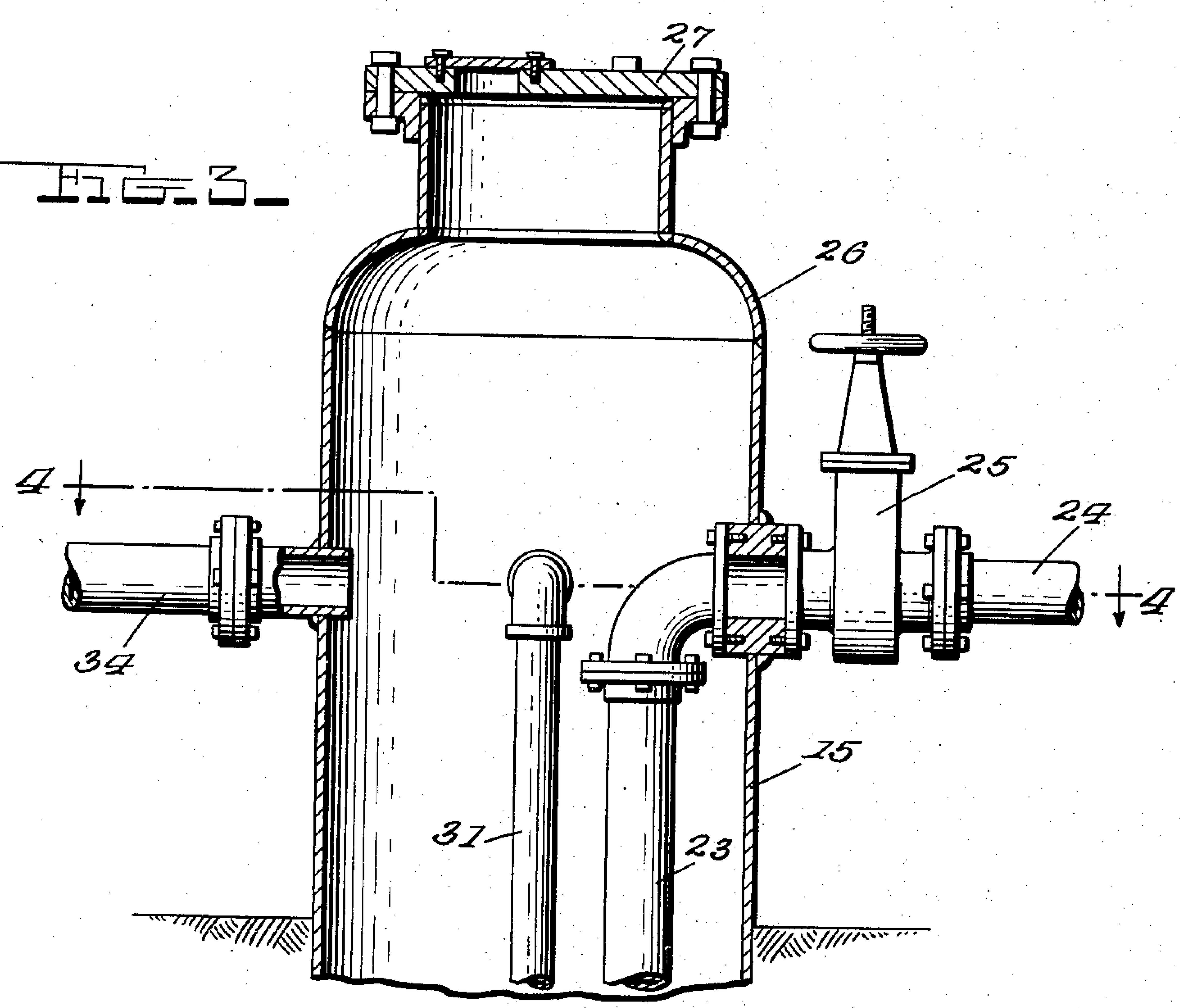


FIG. 4

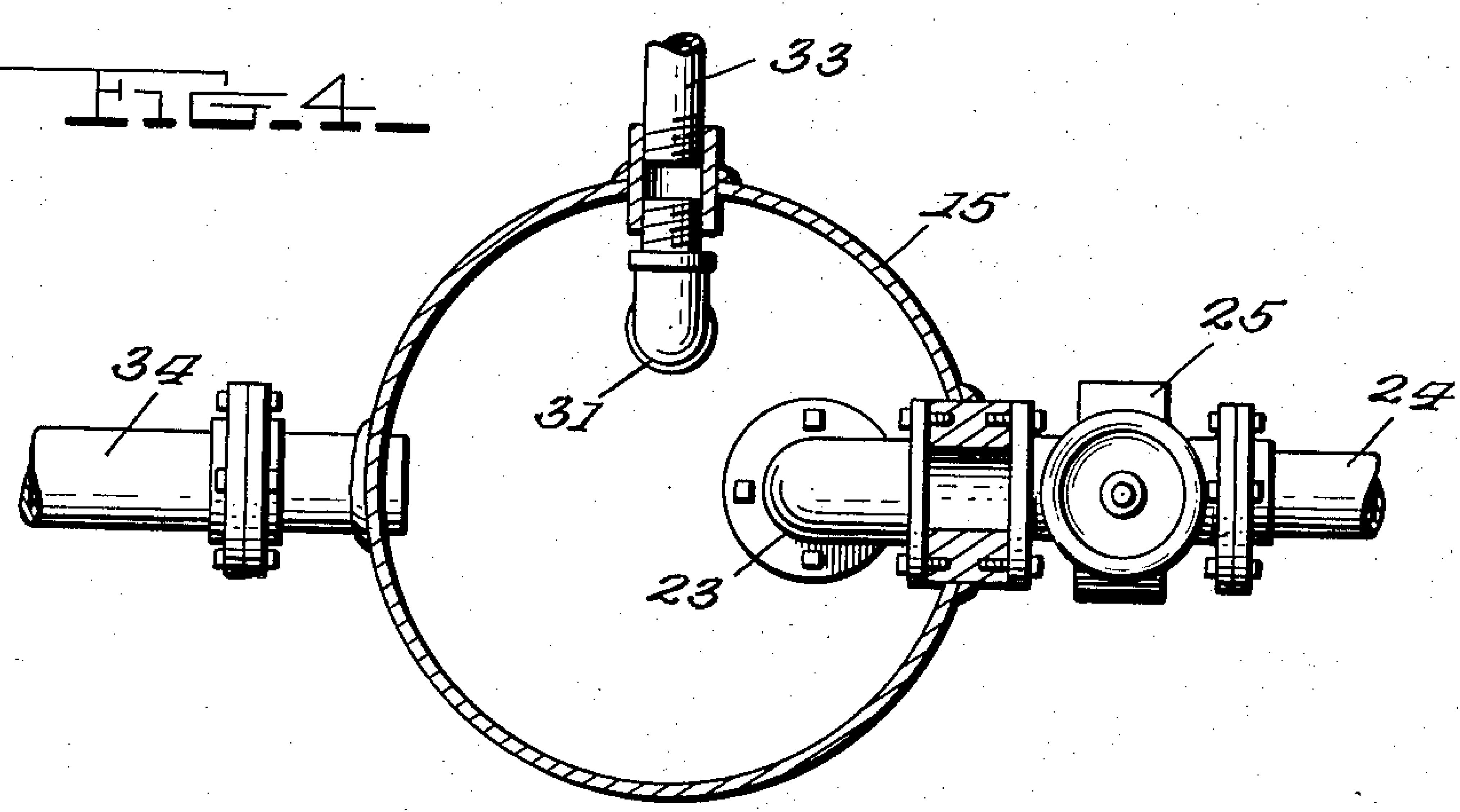


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FIG. 5

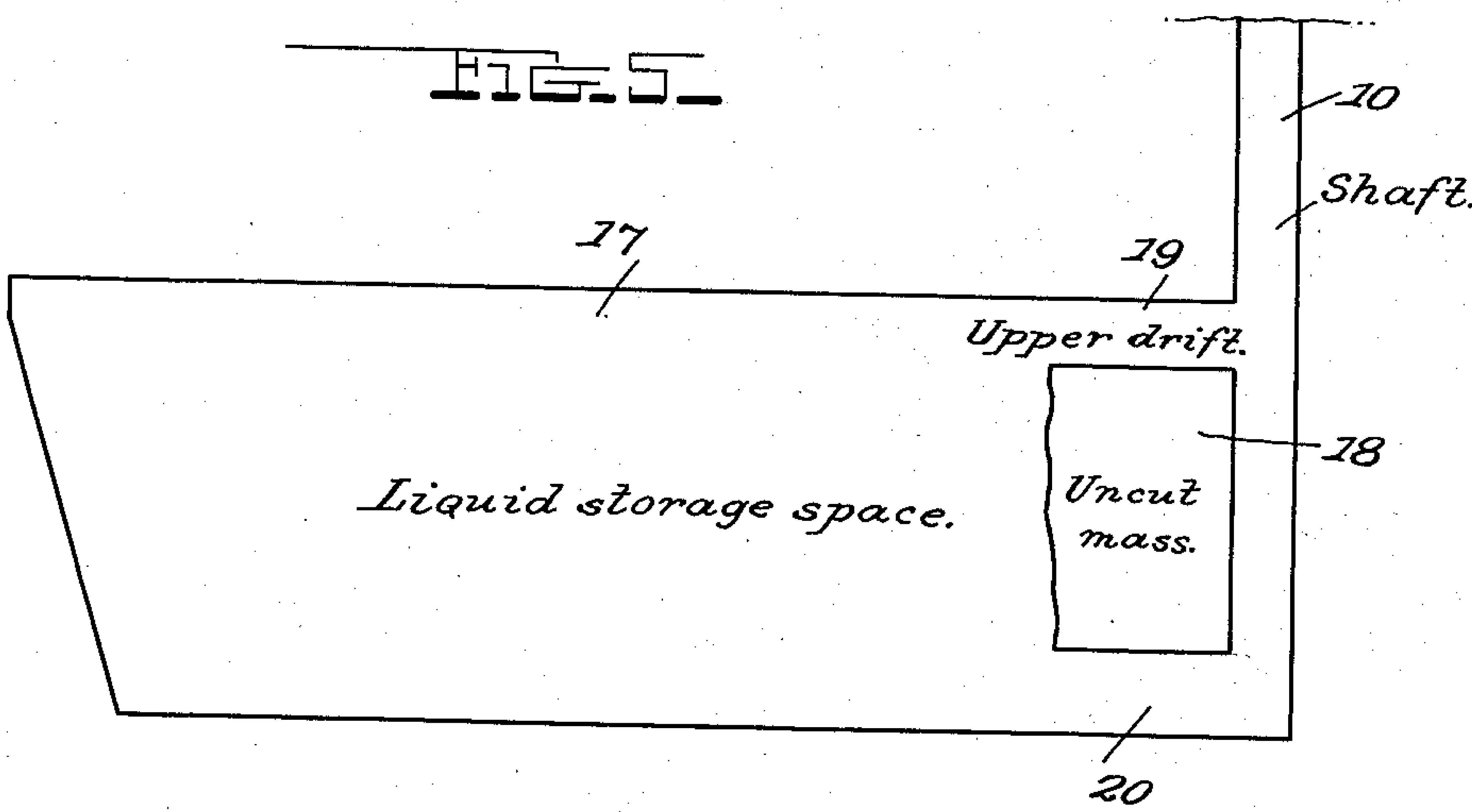



FIG. 6

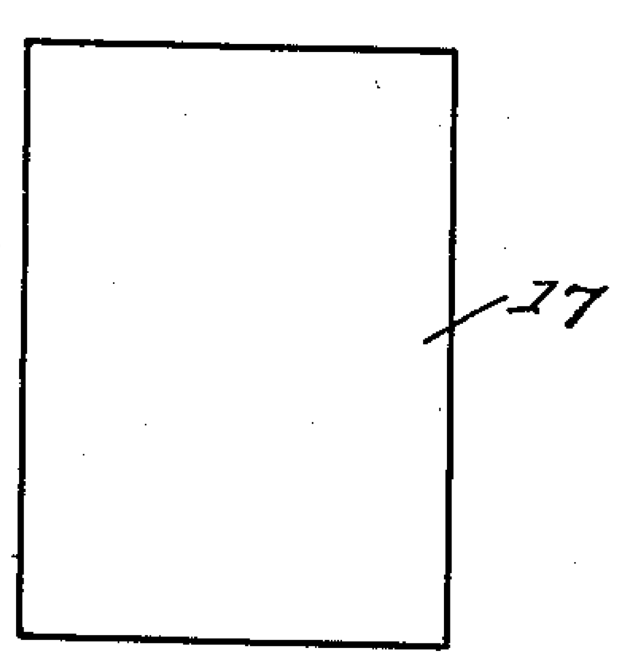



FIG. 7

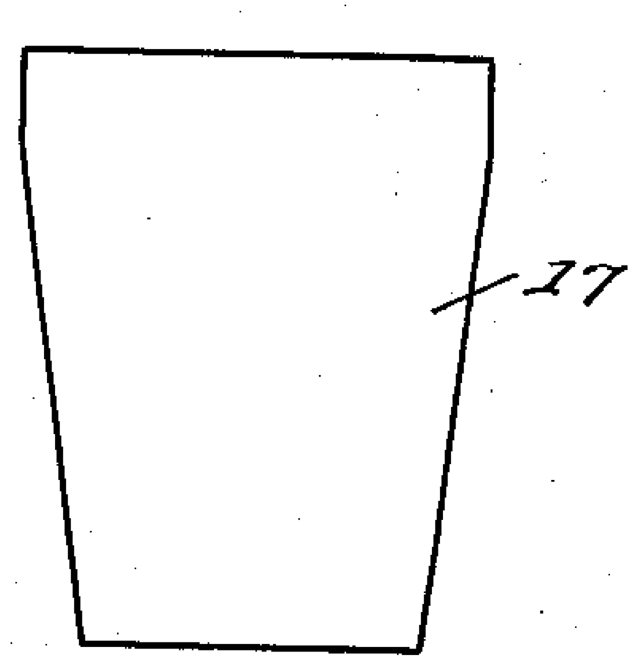



FIG. 8

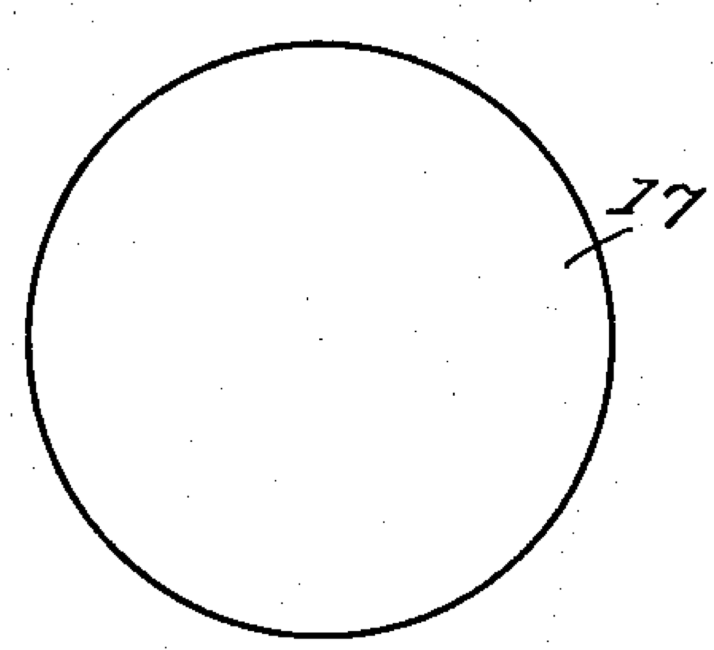
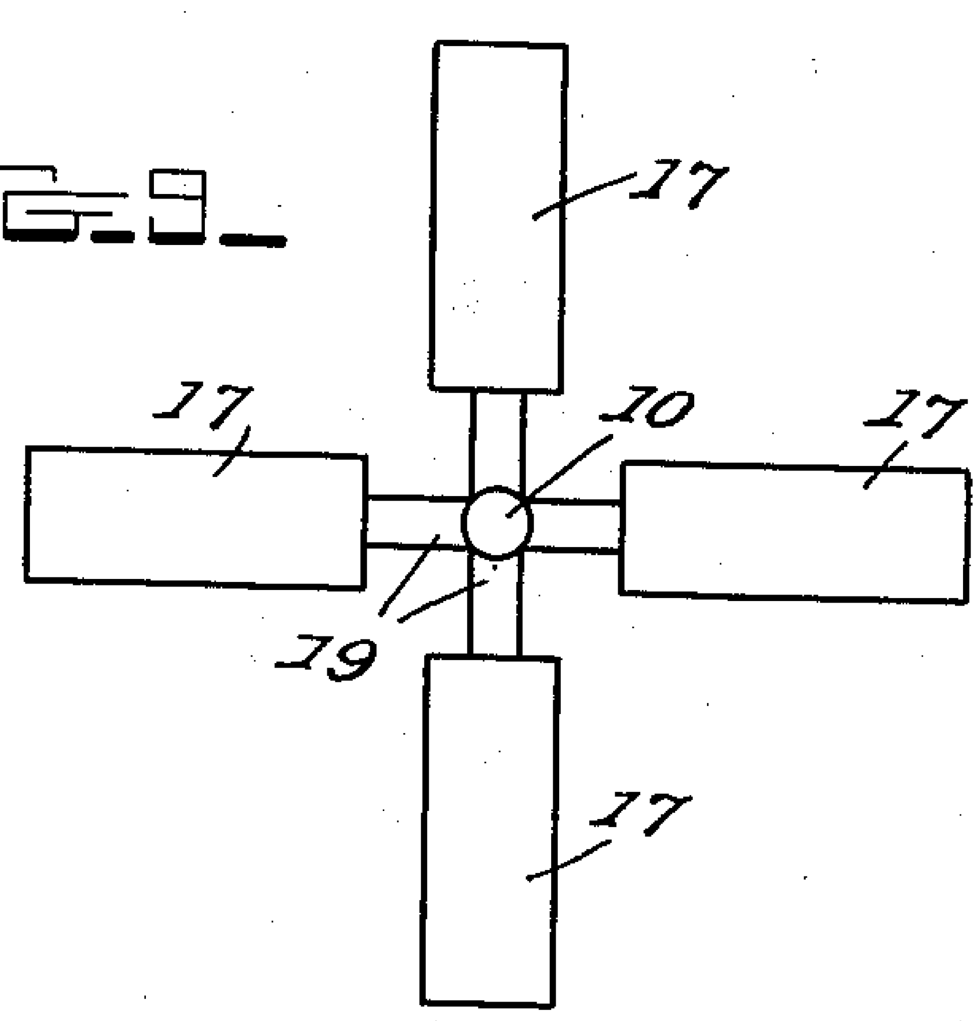



FIG. 9

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## UNDERGROUND LIQUID STORAGE FACILITY AND THE METHOD OF SELECTING AND PREPARING THE SAME

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13 Claims. (Cl. 61—40)

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My invention consists in new and useful improvements in underground liquid storage facilities and the method of selecting and preparing the same, and although it may be used for any liquid products, it has been primarily designed for use in connection with such products as liquified petroleum gas and the like.

It has been generally customary in the past to store liquified petroleum gas in steel storage tanks and containers located above ground which has not only entailed considerable expense in construction and maintenance, but has been attended by fire hazard and danger to personnel and property because of exposed equipment. Furthermore, the shortage of steel from time to time has created a definite problem both in construction and maintenance of above ground storage equipment.

Although some efforts have been made to the end of underground storage facilities, most of those with which I am familiar have not been practical because of the expense involved in lining underground caverns with metal or concrete walls, and the cost of the type of equipment used.

It is therefore the object of the present invention to provide underground liquid storage facilities designed to take advantage of certain geological formations inherent in the earth which render unnecessary the lining of the storage cavern and make it possible to operate the same with a minimum of installation and maintenance costs.

Another object of the invention is to provide underground liquid storage facilities wherein the only equipment exposed above ground is the control dome, thereby not only minimizing fire hazards but insuring to a large extent against damage by bombs and other violence.

With the above and other objects in view which will appear as the description proceeds, my invention consists in the novel features, herein set forth, illustrated in the accompanying drawings, and more particularly pointed out in the appended claims.

Referring to the drawings in which numerals of like character designate similar parts throughout the several views,

Figure 1 is a transverse sectional view of an open shaft drilled in a typical geological formation suitable for use in constructing my improved storage facility.

Figure 2 is a similar view on an enlarged scale, showing the casing and conduits installed in the shaft.

Figure 3 is a sectional view showing the above ground control dome.

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Figure 4 is a sectional view taken on line 4—4 of Figure 3.

Figure 5 is a diagrammatic illustration of a vertical, longitudinal section of a typical shaft and storage cavern.

Figures 6 to 8, inclusive, are illustrations of various wall profiles which may be used for storage caverns, and

Figure 9 is a diagrammatic illustration of a method of providing a plurality of storage caverns with a common control system.

In practicing my invention, it is first desirable to drill one or more cores by conventional core-drilling methods in the general location where the facility is to be installed, so as to select a geological formation having the proper physical characteristics and located at the proper depth underground to serve as a storage cavern.

Of first consideration is the depth of the excavation to be used and this is determined by the geological information available concerning the ability of the overburden to retain pressure. As before stated, I am primarily concerned with the storage of liquid petroleum gas and I have found that a safe minimum depth is one foot per pound of pressure on the material to be stored. For example, for a pressure of 100 pounds (gauge) an excavation or storage cavity should be located at least 100 feet below ground. This may be varied to some extent in cases where the roof formation is of sufficient strength to act as a confining medium as well as an overburden, such, for example, as solid limestone or solid granite.

It is also necessary that the storage cavity to be excavated have a roof stratum consisting of a formation which is impermeable, hard, and substantially free of fractures, and one having sufficient beam strength to support the necessary overburden. An example of a suitable formation for a roof structure would be massive limestone.

Of equal importance are the properties required for the walls of the excavation which should also be impermeable, reasonably dry, and devoid of impurities or properties which might have a deleterious effect upon the liquid stored. A suitable formation for the cavern walls would be tight, sandy, shale to shaly sandstone and silty grey shale. This formation is dry, non-waterbearing, tight, and will not effect the stored materials.

It is desirable, although not necessary, that the cavern formation be followed immediately below by a hard formation suitable for a cavern floor, such, for example, as hard brittle limestone. However, if the walls of the cavity possess the desired properties, a special floor formation per se, is not required.

In Figure 1 of the drawings I have illustrated a typical geological formation composed of successive strata of various characteristics in which a shaft has been drilled. In the drawings, 10 represents the open shaft and the first suitable roof formation which is located 100 feet below ground is the hard, brittle limestone stratum 11. It will be noted, however, that immediately following the stratum 11 is soft grey shale, sandstone, and soft flaky carbonaceous shale with a stratum of hard brittle limestone interposed. With the exception of the intermediate layer of the limestone, these strata are waterbearing and the carbonaceous shale would have a deleterious effect upon the product to be stored because of its sulphur content.

Thus, it will be seen that the first succeeding suitable roof structure which is sufficiently deep to provide the necessary overburden and is in turn succeeded by a sufficient depth of desirable formation for cavity walls, is the stratum 12 of massive limestone. Following this stratum 12 is a relatively deep stratum composed of tight, sandy shale to shaly limestone and silty grey shale, represented by the numeral 13, and this is followed by a hard brittle limestone stratum 14 well adapted to serve as a cavern floor. The stratum 13, being of sufficient depth and possessing the necessary properties, is therefore selected for the location of the cavern to be excavated.

The first step after drilling the open shaft 10 and locating the position for the cavern, is to install a main casing 15 as will be seen from Figure 2. This casing is of sufficient diameter to serve first as a means of ingress and egress during the subsequent mining operation in excavating the cavern and, following this operation, is permitted to remain in the shaft for connection to a casing extension 15a and to house the eduction equipment as will hereinafter appear. Preferably the casing 15 and its extension 15a are approximately 36 inches in inside diameter.

The main casing 15 is lowered to the proper depth in the shaft 10 preferably about one foot below the under face of the roof rock 12, and is "squeeze cemented" from the bottom of the roof rock to the surface of the ground. This "squeeze cementing" is performed by the usual oil field practice, that is, the shaft is filled with the proper quantity of cement and water is then forced through the casing to squeeze the cement out of the bottom of the casing and back up around the outside thereof, filling all spaces and crevices and tightly sealing the periphery of the casing in the shaft, from the roof rock 12 to the ground surface, as shown at 16 in Figure 2. The cement is then allowed to set and attain the required strength prior to testing the seal.

In order to test the seal so as to determine within a reasonable degree of accuracy, whether or not an excavation will be successful, a temporary cap is placed on the top of the casing 15 and a hydrostatic test is conducted on the formation and cement seal. This test is conducted by the usual methods and need not be described in detail. If the results of the test are satisfactory, the excavation of the cavern can be proceeded with. However, if there is any indication of leakage around the cement seal 16, a supplemental sealing structure is installed around the casing, adjacent the underside of the roof formation 12. This will be hereinafter referred to more in detail.



After the main casing 15 has been installed, sealed, and tested, the excavation of the cavern is proceeded with and any modern mining practices may be employed. At the commencement of the mining operation, any excess cement or concrete at the bottom of the casing is drilled out and the shaft is continued in the stratum 13, to the depth of the cavern to be excavated. A cavern 17 of the desired size and shape is then cut horizontally in this stratum by the usual mining practices. This cavern 17 may take various shapes insofar as the profile of its wall structure is concerned, depending upon the nature of the formation of the stratum 13 and giving due consideration to the most economical method of excavation. For example, if the substance of the cavern walls has no tendency to slough or cave in, the walls can be substantially vertical as shown in profile in Figure 6. On the outher hand, in a stratum of dense shale or silty grey shale where there is a likelihood of sloughing, the cavern is excavated with sloping sides to avoid this fault as shown in Figure 7. Figure 8 is simply another example of the profile of the walls of a cavern, in this instance being substantially cylindrical.

In Figure 5 I have illustrated a typical longitudinal cross section of a storage cavern which has been excavated horizontally from the bottom of shaft 10 and wherein an uncut mass 18 is permitted to remain immediately adjacent the lower portion of the shaft 10, with an upper drift 19 extending from the upper extremity of the cavern 17 to the shaft 10 and a passage 20 extending horizontally from the lower portion of the cavern 17 to the bottom of the shaft 10.

After the cavern 17 has been excavated, an extension 15a is welded to the lower end of the casing 15, as shown at 21 in Figure 2. This extension may be lowered into the shaft in sections or in collapsed form and then welded in tubular shape. In its final form the extension 15a is provided with an entrance door or opening 21a in its side wall, at the lower end of the extension, to afford access to the cavern from the casing. Also a vapor opening 22 is cut in the wall of the extension 15a adjacent the upper drift 19, to admit vapor pressure into the space about the level of the liquid to stored in the cavern 17, as will hereinafter appear.

An eductor tube 23 is then installed in the casing 15 and extends from the bottom of the extension 15a, to the ground level where it is connected through the wall of the casing to a liquid discharge conduit 24 having a control valve 25 interposed therein. The top of the casing 15 is closed by a suitable control dome 26, welded to the upper end of the casing 15 and having a removably covered man hole 27 to permit entrance into the casing. The bottom of the eductor tube 23 extends to the lower extremity of the extension 15a and is preferably closed and sealed to a steel plate 28 supported on a concrete base 29 which supports the bottom of the extension 15a. One or more vertical slots 30 are cut in the wall of the tube 23, a predetermined distance above its lower end so as to provide for the admission of stored liquid into the eductor tube, said slots being spaced upwardly from the bottom of the tube a sufficient distance to prevent the admission of water which may underlie the stored liquid. Also extending vertically in the casing 15, is a water siphon pipe 31, the lower end of which terminates at the bottom of the extension in an angularly cut open end 32 so as to expose its inlet opening in a plane below the slot 30 in the eductor tube 23. Thus, water can be withdrawn through tube 31 without including oil in the withdrawal. The upper end of the water siphon pipe 31 is connected through the wall of the casing 15 to a water drain conduit 33, as seen in Figure 4.

An air pressure conduit 34, leading from a suitable source of air or vapor pressure (not shown), is connected to the interior of the casing 15 through a sealed opening in its side wall as shown in Figures 3 and 4, whereby air or vapor under pressure may be introduced into the casing 15 during the discharge of liquid from the cavern 17. This vapor line also serves the reverse function of venting when the cavern is being charged with liquid to be stored.

In operation, the man hole cover 27 is first secured tightly in place and when it is desired to discharge liquified petroleum gas or other liquid stored in the cavern 17, air or vapor under suitable pressure, is introduced through conduit 34 into the casing 15. By means of the vapor opening 22 in the casing adjacent the upper drift 19, the area above the liquid level in the cavity is subjected to the pressure required to force the liquid upwardly through the eductor tube 23 and into the discharge conduit 24.

In storage facilities which are located at extreme depths, it may be advantageous to utilize a pump for withdrawing the liquid from the cavern. However, in most instances, I have found that the use of vapor pressure on the upper surface of the stored liquid is sufficient to effect a satisfactory discharge.

As before indicated, if the concrete seal 16 satisfactorily withstands the hydrostatic test in the initial operations of installing the facility, an additional sealing means is not necessary. However, in some instances a supplemental sealing of the casing is required. Such means is illustrated in Figure 2 of the drawings where 35 represents a flat annular ring of suitable metal which is bolted into the roof structure 12 by means of expansion bolts 36 and surrounds the shaft opening radially beyond the concrete seal 16. In installing the ring 35 the bottom surface of the limestone stratum 12 is ground to a polished sealing fit with the adjacent surface of the ring 35 so that when the expansion bolts 36 are inserted, the ring 35 is maintained in sealing engagement with the under surface of the roof stratum 12. An annular bowl-shaped metallic head 37 surrounds the casing 15 immediately below the ring 35 and its upper edge is welded to the ring while its lower edge is welded to the casing extension 15a. Thus, the pressure in the cavern has a self-sealing effect due to the structure of the head 37 which has a tendency to force the ring 35 into even tighter sealing engagement with the roof stratum 12 so as to prevent leakage through the roof stratum 12 past the casing 15.

In practice, both the ring 35 and the head 37 may be lowered into the shaft in sections of a size to pass through the casing 15, and then welded together prior to installation. It is believed unnecessary to illustrate this particular phase of the operation as it will be clearly understood by those skilled in the art.

Facilities of this nature may be installed individually or a series of caverns may be arranged so as to utilize a common unit of charging and discharging equipment. For example, in Figure 9 I have shown a series of caverns 17 which radiate from a common shaft 10 which is used both in the excavation of the caverns and for the installation of charging and discharging equipment. Obviously, many different arrangements can be employed with equal effect, such, for example, as a series of caverns arranged in parallel rows communicating with a common shaft.

To facilitate the mining operation and to reduce costs, it may be desirable to sink an auxiliary shaft of small diameter such, for example, as 8 or 12 inches, to carry air, drilling tools, water, lights, or other utilities necessary for the operation. Normally this hole is plugged by cement after the excavation has been completed.

It will thus be seen that the use of my improved method and facility enables the underground storage of large quantities of liquified petroleum gas or the like under most economical conditions and with a maximum degree of safety. Furthermore, the vapor loading and unloading system for withdrawing the liquid from the cavern is simple in construction and easy to install and operate. By the use of vapor pressure in discharging the liquid, I eliminate moisture from the product and the stored liquid can be withdrawn at a greater rate per hour.

From the foregoing it is believed that my invention may be readily understood by those skilled in the art without further description, it being borne in mind that numerous changes may be made in the details disclosed, without departing from the spirit of the invention as set forth in the following claims.

I claim:

1. An underground storage facility for liquid under pressure, comprising a vertical shaft extending into the ground, a subterranean cavern having an overburden of a depth of at least one foot per pound gauge pressure on the liquid to be stored formed in the ground, extending outwardly from and connecting into said shaft, said shaft leading from said cavern to ground level, a casing, closed at its upper end, lining said shaft and extending to the bottom of said cavern, an opening to the cavern, at the lower end of said casing, means sealing the casing in said shaft, an eductor tube in said casing and having an inlet opening in its lower end, substantially at the bottom of said casing, a discharge conduit connected to the upper end of said eductor tube, and means for discharging liquid from said cavern through said eductor tube.

2. An underground storage facility as claimed in claim 1, including means for introducing a gaseous pressure medium through said casing to the area of said cavern above the liquid level therein, to displace liquid through said eductor tube.

3. An underground storage facility as claimed in claim 1, wherein said casing is of such transverse dimensions as to afford entrance and egress with respect to the cavern and its lower end is provided with a cut out portion adapted to serve as an entrance doorway to the cavern.

4. An underground storage facility as claimed in claim 3, including means for introducing a gaseous pressure medium through said casing to the area of said cavern above the liquid level therein, to displace said liquid through said eductor tube.

5. An underground storage facility as claimed

in claim 3, including a second opening in said casing in a plane above the level of the liquid stored in the cavern, and means for introducing a gaseous pressure medium through said casing and second opening, to the area above the liquid level in said cavern, to displace said liquid through said eductor tube.

6. An underground liquid storage facility as claimed in claim 1, wherein the inlet opening in said eductor tube is spaced vertically from the bottom of the cavern to prevent the entrance of water which may underlie the liquid stored in said cavern.

7. An underground liquid storage facility as claimed in claim 6, including a water siphon tube extending from the bottom of said cavern to ground level and having an inlet opening at its lower end disposed in a plane below the plane of the inlet opening to said eductor tube.

8. An underground storage facility for liquids under pressure, comprising a subterranean cavern having a relatively deep overburden, said cavern being bounded at its upper extremity by a geological roof rock formation which is hard, impermeable, and substantially free from fractures, and having a thickness and beam strength to support the weight of said overburden, the cavern being formed in a selected stratum which is impermeable, substantially dry, and free from properties which would affect the quality and consistency of the liquid stored therein a shaft leading from said cavern to ground level, a casing closed at its upper end, lining said shaft, and opening into said cavern in a plane above the level of the liquid stored therein, means sealing the casing in said shaft, an eductor tube extending through said casing and having an inlet opening at its lower end substantially at the bottom of said cavern, a discharge conduit connected to the upper end of said eductor tube, and means for discharging liquid from said cavern through said eductor tube.

9. In an underground storage facility as claimed in claim 8, a supplemental seal for said casing comprising a flat annular ring in sealing engagement with the under surface of said roof rock formation around said shaft, means securing said ring to said roof rock formation, an annular, substantially bowl-shaped head surrounding said casing beneath said ring and sealed respectively at its upper and lower extremities, to the under side of said ring and the periphery of said casing.

10. In underground storage facility as claimed in claim 8, a supplemental seal for said casing comprising a flat annular ring engaging the under surface of said roof rock formation around said shaft, with a ground and polished fit, means securing said ring to said roof rock formation, an annular, substantially bowl-shaped head surrounding said casing beneath said ring and sealed respectively at its upper and lower extremities, to the under side of said ring and the periphery of said casing.

11. In combination with a subterranean cavern having a vertical shaft extending therefrom and a casing lining said shaft, means sealing said casing with respect to said shaft comprising a flat annular plate surrounding said casing and in sealing engagement with the roof of the cavern, means securing said plate in sealing engagement, and an annular, substantially bowl-shaped head surrounding said casing beneath said plate and sealed respectively at its upper and lower extremities, to the undersides of said plate and the periphery of said casing.

12. The method of preparing an underground pressure fluid storage facility, comprising drilling a core to a geological formation having a hard rock stratum possessing suitable roof properties and a depth to provide a sufficient overburden to retain pressure of the fluid to be stored, and immediately followed by a relatively deep second stratum which is dry, non-permeable by the fluid to be stored, and devoid of impurities which will affect the fluid to be stored, sinking a mining shaft along the core bore, installing a casing in said shaft, sealing said casing with respect to the surrounding formation from the bottom of the shaft to ground level, excavating an offset storage cavern in the second stratum from a point adjacent the lower portion of said shaft, installing a liquid conducting discharge pipe through said casing from ground level to the bottom of the casing, and closing the top of said casing.

13. The method as claimed in claim 12, including sealing the casing by introducing therein a quantity of cement in fluid state and then forcing water under pressure, through said casing to squeeze said cement out through the lower end of the casing and up between the outer wall of the casing and the surrounding shaft.

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