

[54] **MEANS FOR THE UNDERGROUND STORAGE OF LIQUIFIED GAS**

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[51] Int. Cl. **F17c 7/02**

[58] Field of Search **62/45; 61/0.5; 252/269**

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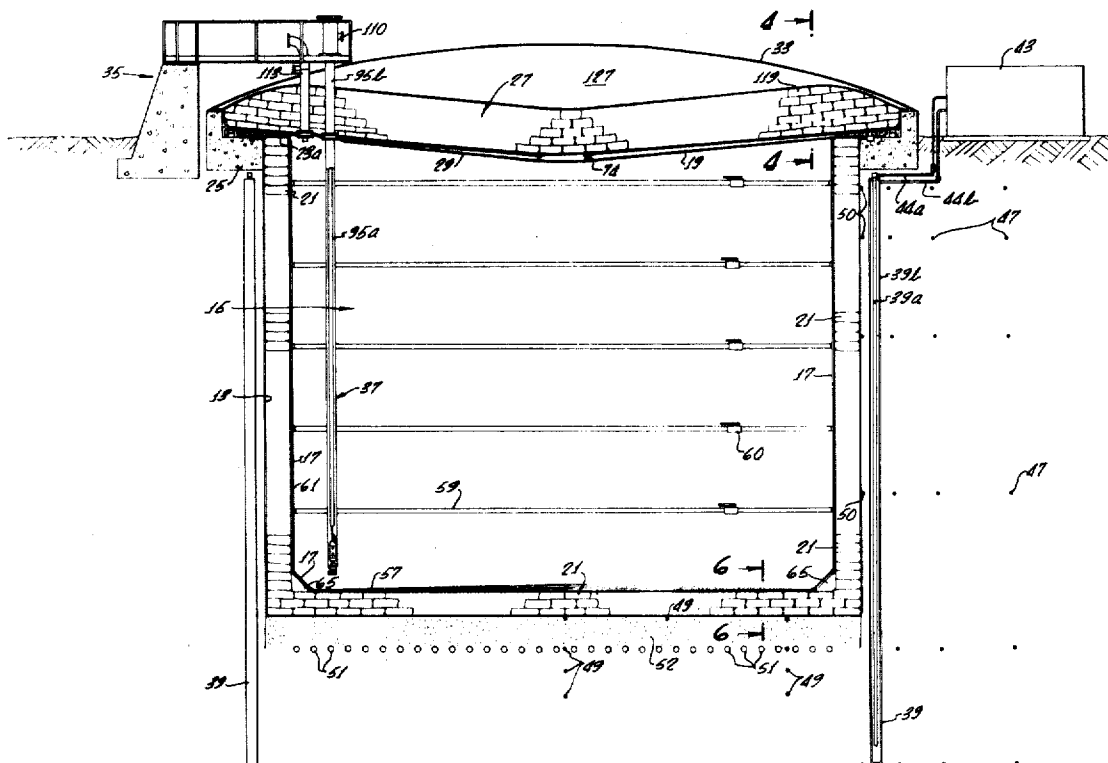
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[57] **ABSTRACT**

Liquified gas is stored underground in a large double walled container seated in an opening in the earth's surface. Between the walls of the liner, thermal insulation is distributed in a continuous layer along the floor and wall of the opening. A diaphragm is supported across the top of the opening with a seal being provided between the diaphragm and the double walled liner to form a container for the liquified gas. Surrounding the lip of the opening is a concrete ring across which a net of cables is stretched to support a thermally insulating ceiling. A cooling system is provided for freezing the earth to aid in the excavation of the opening and this system is subsequently used to maintain the wall and floor of the opening frozen to a controlled thickness by cooling them in response to a rise in the temperature of the surrounding earth above a predetermined temperature level.

Also disclosed are various techniques for constructing a storage tank of the type described.

16 Claims, 10 Drawing Figures



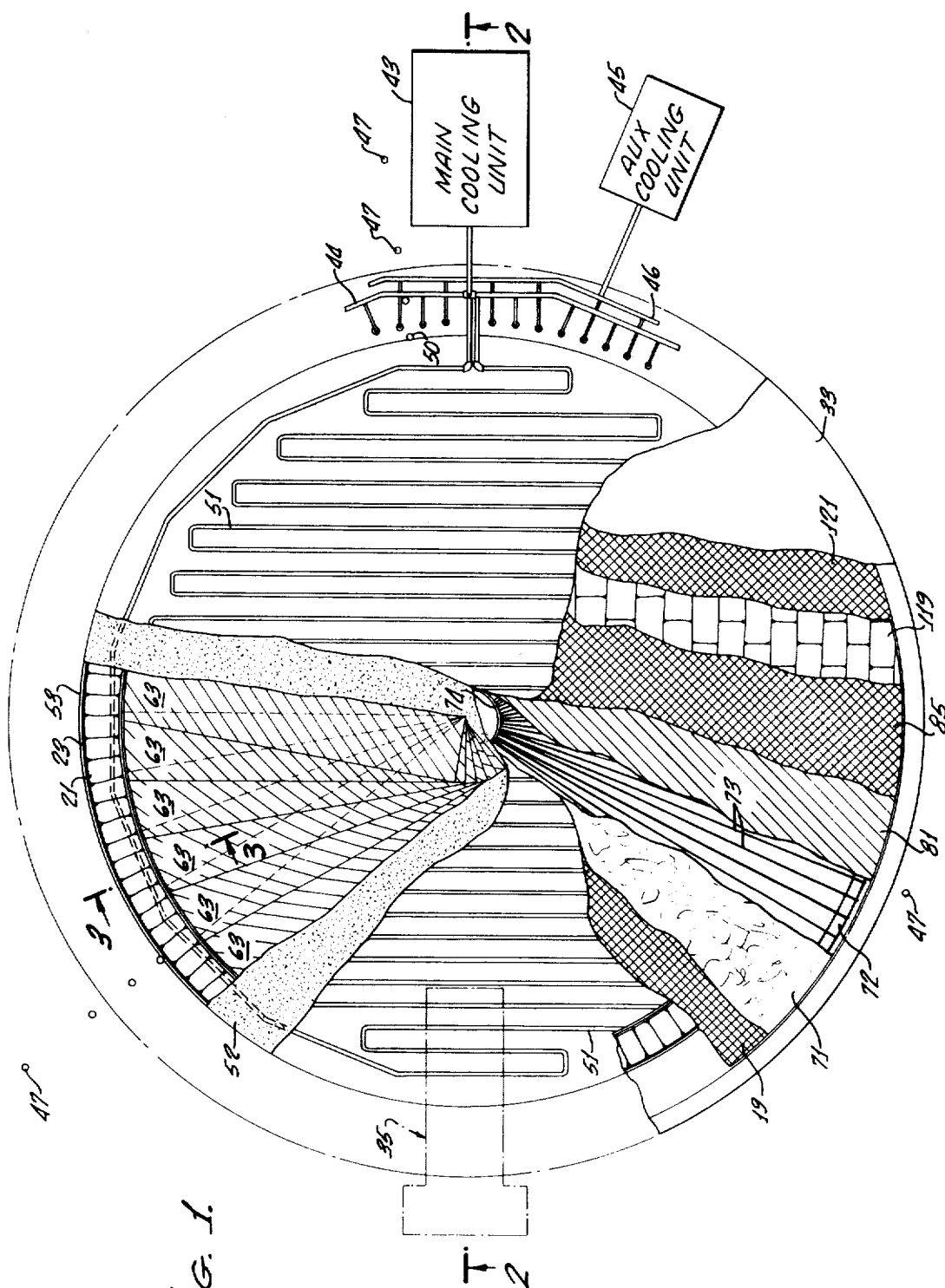
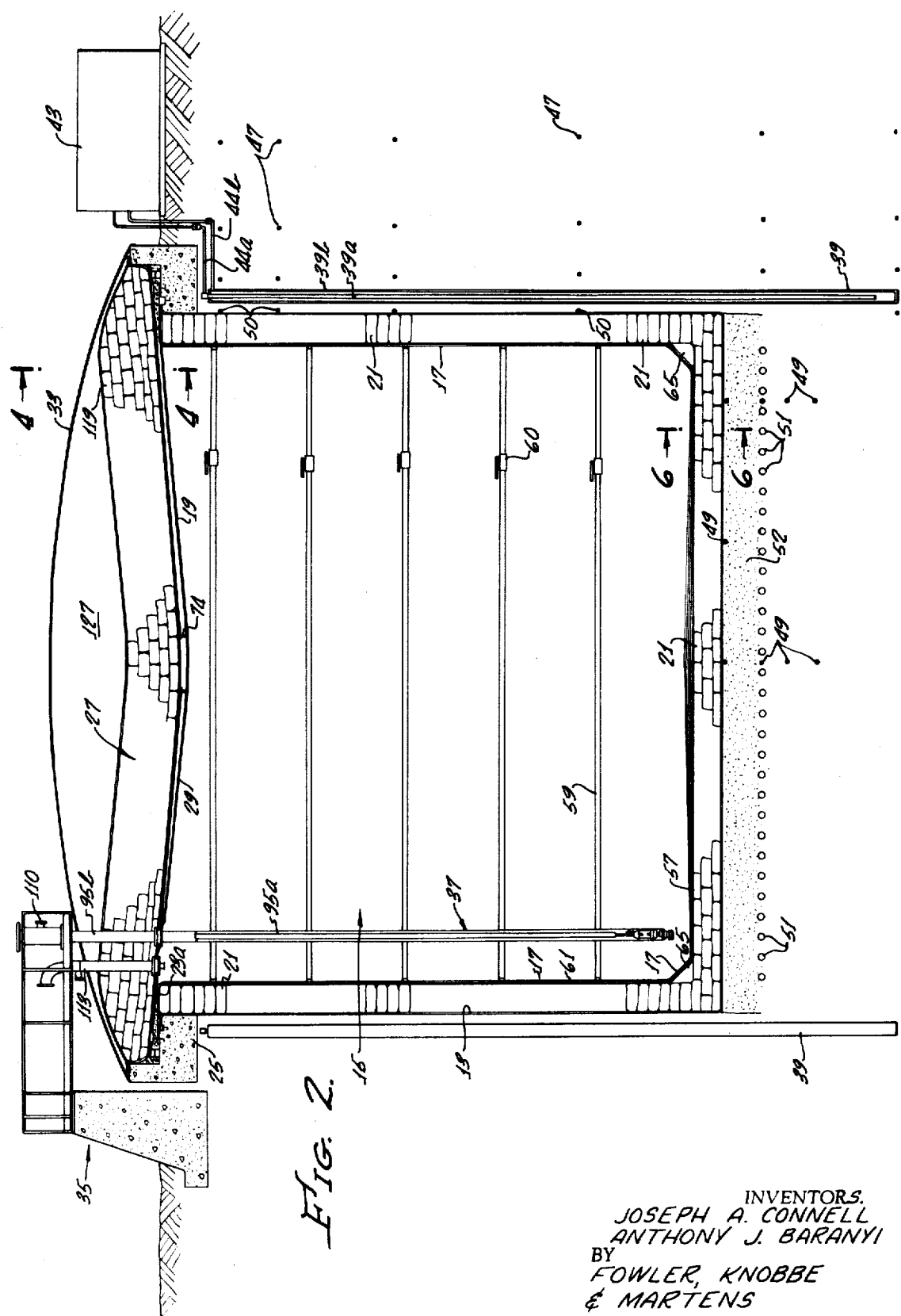


FIG. 1.

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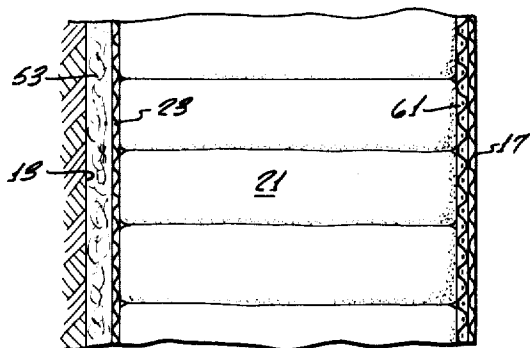


FIG. 3.

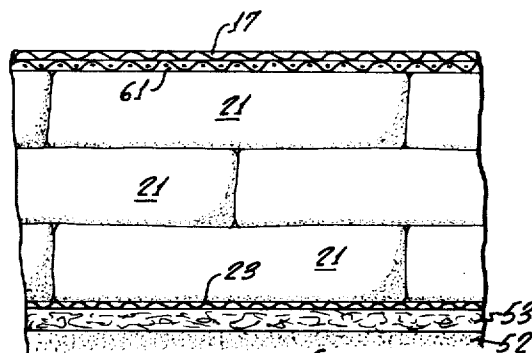


FIG. 6.

FIG. 4.

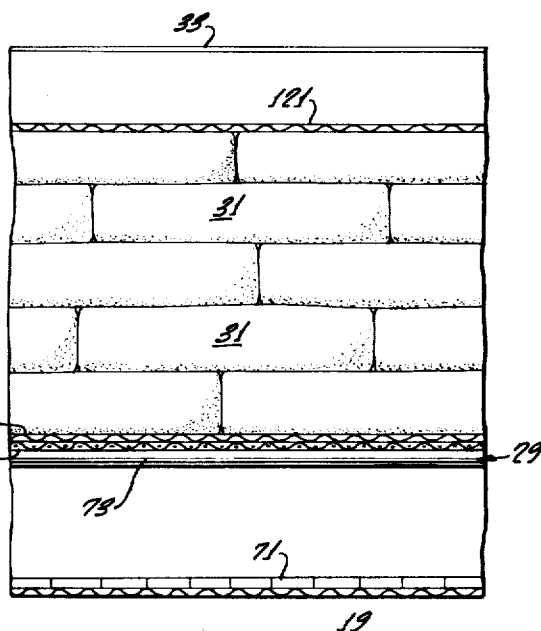
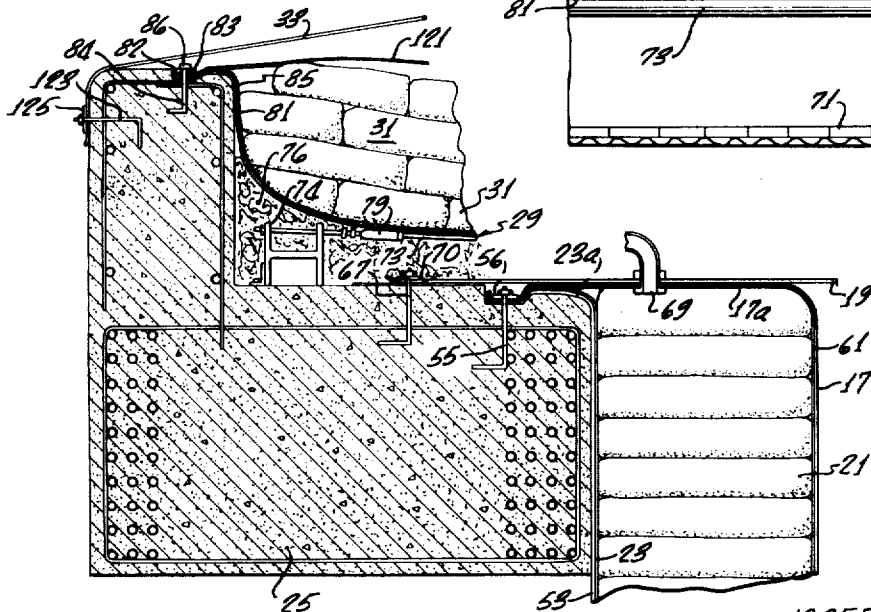


FIG. 5.



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FIG. 5a.

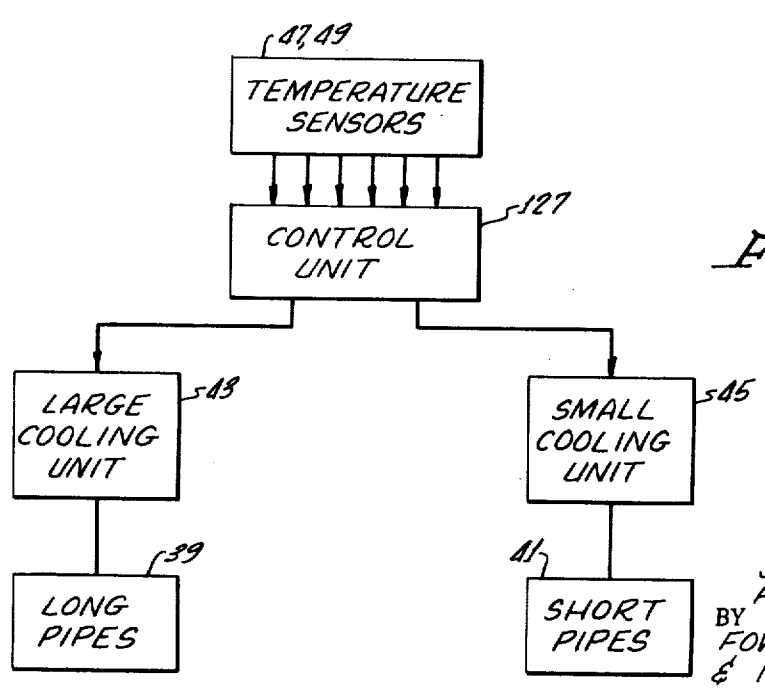
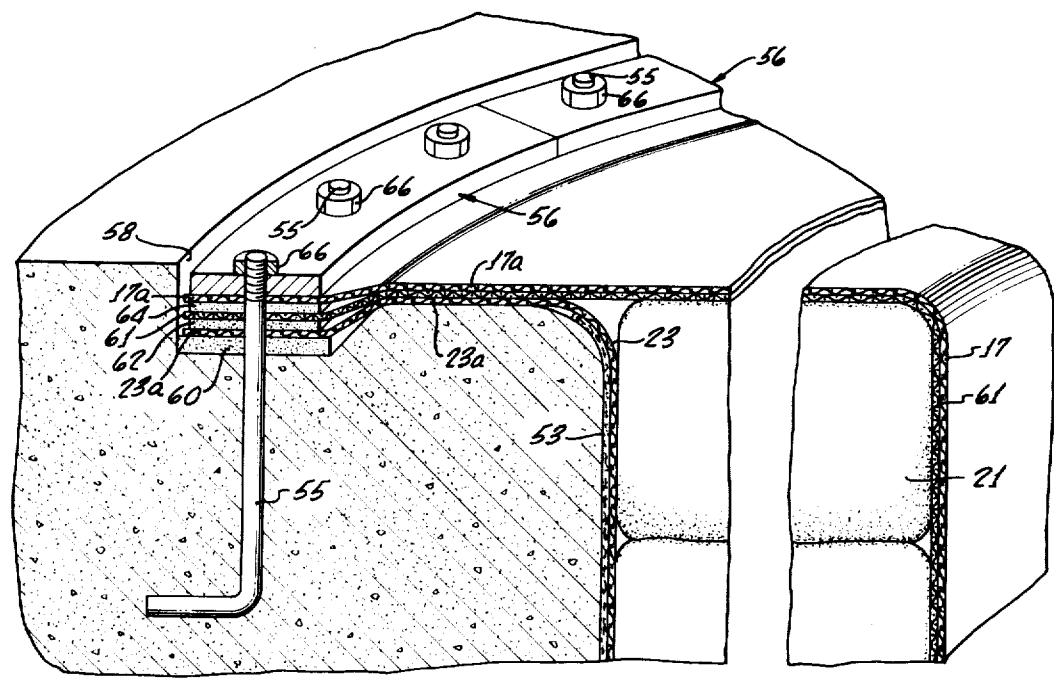


FIG. 9.

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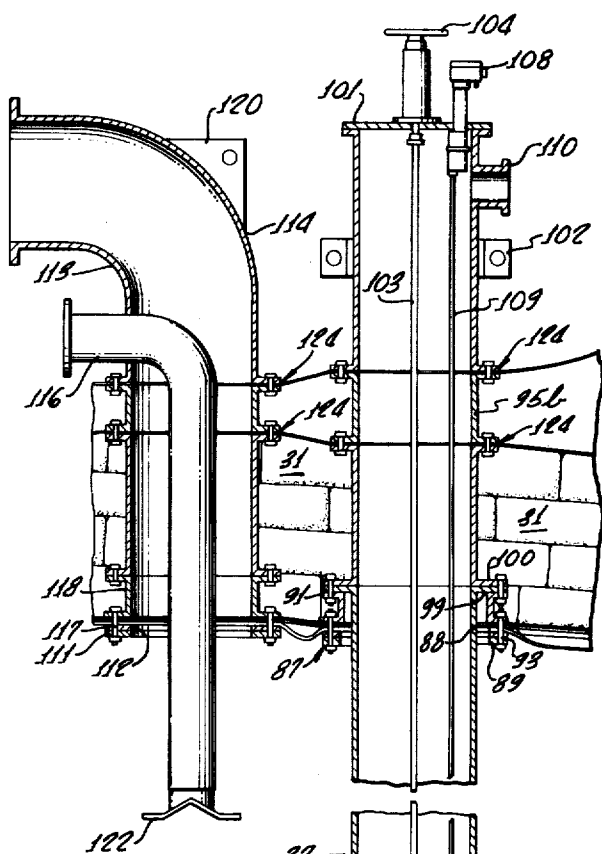
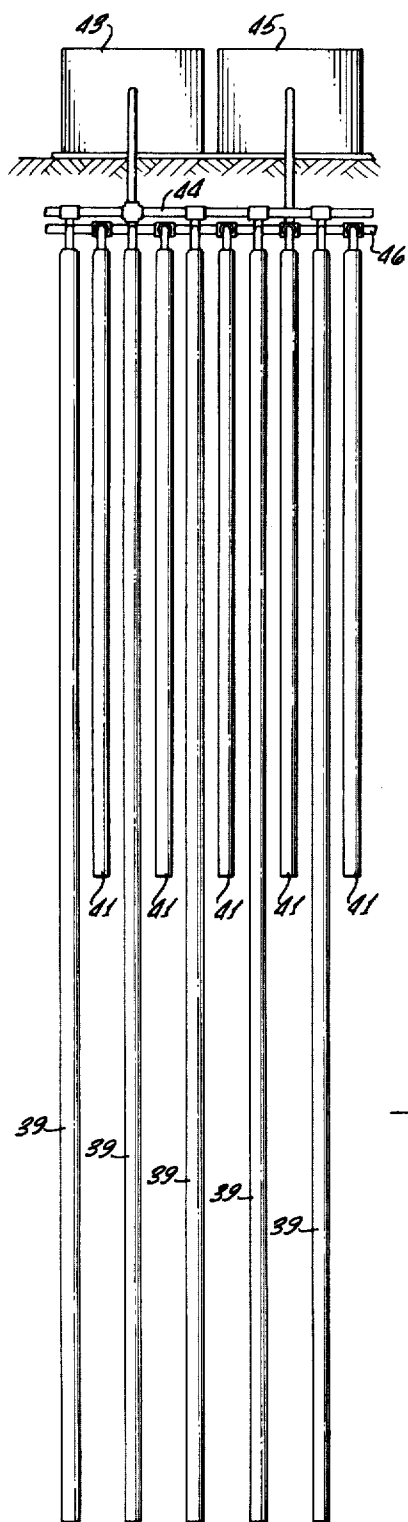
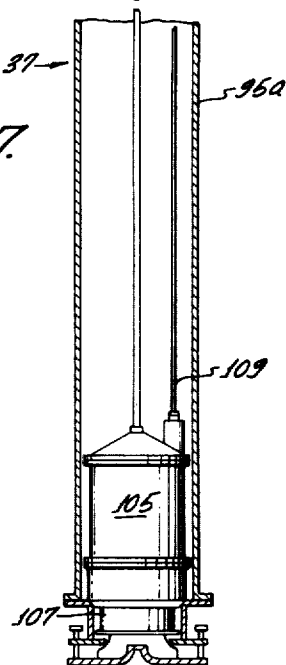


FIG. 7.

FIG. 8.



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MEANS FOR THE UNDERGROUND STORAGE OF LIQUIFIED GAS

The present invention relates to the storing of large quantities of liquified gas, most advantageously natural gas and in particular to the storing of such liquified gas underground.

Three different concepts have been utilized in existing cryogenic liquified gas storage systems. These concepts have respectively involved the use of above ground tanks, below ground tanks, and in ground storage. Above ground tanks are generally constructed with a double wall having insulation between the inner and outer walls. The inner tank is constructed of a material capable of withstanding cryogenic temperatures. Such materials include aluminum, stainless steel, 9 percent nickel steel and reinforcing concrete. The outer tank may be made of carbon steel since the insulation protects it from the cryogenic temperatures.

Above ground tanks have several disadvantages. First, they are expensive to construct. Secondly, they require a diked area around the tank to contain the liquid in the event of tank failure, necessitating the use of additional land. Thirdly, in many urban and suburban areas, above ground tanks are not permitted because of their appearance.

To overcome the disadvantages of above ground tanks, several methods of constructing below ground tanks have been attempted. Most of these involve the use of a concrete tank submerged wholly or partially in the ground. In a few cases metal tanks have been so used. In several cases a void was left between the below ground tank and the surrounding earth and this void was then filled with insulating material. Below ground tanks also suffer from the disadvantage of being expensive. Additionally, since the submerged tanks are rigid structures, steps must be taken to safeguard against frost heaving by the surrounding earth which might cause the tank to rupture.

The above problems have lead to several attempts to store liquified gases and particularly liquid natural gas in a frozen hole in the ground. In most of these cases, the earth itself has been the liquid container, while in a few instances a flexible moisture-impervious liner has been incorporated. Although the heat leak into these tanks is usually excessive, a few of them have enjoyed success. A principal problem with this approach is that the success or failure of the project depends almost entirely on the effect that cryogenic temperatures have on the soil and rock formation in which the container is constructed. In several cases, subjecting the soil and rock to cryogenic temperatures has resulted in fracture and fissure formations which increased heat leak to the point where the tank was not useable and had to be abandoned.

The present invention is directed to achieving the advantages of underground storage, such as a lower profile and a lower cost, while avoiding the past problems of this approach, such as damage to the tank walls by frost heaving. In accordance with the present invention, a tank is constructed in the ground either in an existing hole or, if necessary, in a specially excavated opening. Preferably, the excavation is accomplished by the known technique of freezing an earthen wall around the area which is to be excavated and then excavating the unfrozen center.

A principal reason for selecting ground freezing as an aid in excavation is to permit the use of vertical side walls without the need for piling.

In accordance with a particular feature of the present invention, ground freezing is used for more than a mere aid in excavation. The frozen ring around the excavated opening is maintained as a permanent structural support for the tank. Additionally, after the hole has been dug, its floor may also be frozen and maintained frozen by means of a heat exchanger buried in the floor of the opening. In this manner, a frozen shell of earth is provided around the storage tank for stable structural support.

Inside the opening a double walled, thermally heavily insulated container is installed. The container is comprised principally of an outer liner of moisture-impervious material whose size and shape are such as to conform to the wall and floor of the opening. Inside this liner, stacked upon the floor and wall of the opening are cryogenically stable, porous bags filled with thermal insulation, such as Perlite. A second bucket-shaped liner is installed inside the thermal insulation and is sealed at its top to the outer liner. Preferably, both liners are suspended from a concrete ring which surrounds the lip of the opening and which is installed prior to its excavation. The container is capped by a diaphragm which is suspended from the concrete ring, and a thermally insulating ceiling is installed above the diaphragm, this ceiling also being preferably supported by the concrete ring.

The above described structural features have several important advantages. Among these is the fact that the container structure inside the opening is relatively inexpensive when compared with a solid shell of concrete or metal. Moreover, since the container is highly flexible, it is less susceptible to leakage due to fracture. The packing of thermal insulation into bags of cryogenically stable porous material insures that the thermal insulation will not be crushed or ruptured when the container is filled with liquified gas. This has tended to be a problem in several previously conceived in-ground tanks in which thermal insulation was formed by pouring a formed wall of polyurethane or some other form of insulating material. This material, when subjected to cryogenic temperatures, tends to contract, causing the insulation to pull away from the earthen wall of the opening and to be crushed by the weight of the stored liquid in the container pressing against the insulation. Moreover, by using a porous material for the bags, the problem of air escaping from the bag as the bag is compressed by the weight of insulation above it as well as by the weight of the liquid in the tank is eliminated. Another advantage of the proposed construction of the double walled container is that the air initially captured between its walls may be replaced either by a vacuum or by an inert gas, thereby retarding the deterioration of the insulation.

Another feature of the subject invention is that the thickness of the frozen shell of earth around the container of liquified gas is maintained within predetermined limits. This is achieved by the use of a set of temperature sensors installed into the ground around the opening to some distance from its frozen wall and also underneath the floor of the opening. Temperature sensors and freeze pipes are installed around the opening

at the same time. Additional temperature sensors are installed along the inner wall and base of the opening after its excavation is complete. The sensors are used to control a cooling system connected to the freeze pipes and, by either automatic control means or through manual adjustments, the output of the cooling system is modified in response to the readings obtained from the temperature sensors. Toward this end, the thermal insulation which is between the inner and outer liners of the container is made sufficiently thick so that the heat loss from the earthen shell surrounding the opening into the container of liquified gas is not enough to maintain the earth around the opening frozen to any substantial distance. Rather, the storage tank is so designed that it is necessary to run the cooling system in order to maintain the wall and floor of the opening frozen to a desired distance. This feature of the invention tends to prevent ice lenses from forming around the opening and lifting or shifting the entire tank.

By using a separate cooling system to maintain a frozen earthen shell around the container of liquified gas the rate of heat flow from the earth into the container is reduced below the level which would exist if only the insulation were relied upon for this purpose. This in turn reduces the boil-off rate of the liquified gas in the container to a desirably low level.

The unique insulating system of the present invention is useful, however, even if the opening in which the container is retained is not surrounded by frozen earth but is instead in a solid rock formation, because it serves to insulate the rock formation from the low temperature of the liquified gas being stored, thereby avoiding the problem of fracture and fissure formation which has plagued in-ground tanks in the past.

The present invention and its advantages will be more clearly understood with reference to the following description of a preferred embodiment thereof taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a plan view, partially cut away, of a storage tank incorporating features of the present invention;

FIG. 2 is a cross-section along line 2—2 of the storage tank illustrated in FIG. 1;

FIG. 3 is a sectional view of a wall of the storage tank illustrated in FIG. 2, taken along line 3—3;

FIG. 4 is a sectional view of the ceiling and roof of the storage tank illustrated in FIG. 2, taken through line 4—4;

FIG. 5 is an enlarged sectional view of the supporting concrete ring surrounding the mouth of the opening which houses the storage tank illustrated in FIG. 2;

FIG. 5a is an enlarged perspective cross-sectional view of a portion of the concrete ring of FIG. 5 showing more clearly the manner in which the several layers of the storage tank are anchored upon the ring;

FIG. 6 is a sectional view of the floor of the storage tank of FIG. 2, taken through line 6—6;

FIG. 7 is an enlargement of a portion of FIG. 2 to illustrate some of the details of the submerged pump used in the illustrated storage tank and the manner in which it is installed therein;

FIG. 8 is a side view of a few of the freeze pipes which are sunk into the earth in a circular array and through which a refrigerant is pumped to create a frozen shell of earth to provide structural support for the storage tank of FIGS. 1 and 2; and

FIG. 9 is a block diagram illustrating a cooling system for initially freezing the floor and walls of the opening and for maintaining them frozen to a constant thickness.

An underground storage tank incorporating features of the present invention is illustrated in FIGS. 1, 2, and 5. It is comprised principally of an opening 13 in the earth's surface housing a double walled container 15. The container is shown to be fabricated of a bucket-shaped inner liner 17 capped by a diaphragm 19. The inner liner 17 of the container is surrounded by insulating pillows 21 comprised of thermal insulation packed in bags, and the pillows 21 are in turn held within an outer bucket-shaped liner 23 which serves to prevent moisture from the earth from seeping into the thermal insulation. A concrete ring 25 surrounds the lip of the opening 13 and serves as a structural support for the ceiling 27. The latter includes a net 29 of cables upon which several layers of thermally insulating pillows 31, typically bags packed with thermal insulation are distributed. If desired, a roof 33 supported by an inert gas such as nitrogen may be anchored upon the ring 25 to prevent damage to the ceiling 27. Cryogenic fluid is pumped out of the storage tank by a submersible pumping system 37 which is suspended into the storage tank from a cantilever support structure 35.

As mentioned previously, the storage tank of the present invention may be either in an opening which is in a rock formation, in which case freezing of the ground is not required, or it may be formed in an opening in soil in which case it is desirable that the ground be frozen both as an aid in construction and to provide structural strength during operation of the tank. The tank which is illustrated in the FIGURES is of the latter type. The first step in constructing the subject storage tank is to investigate the soil conditions at the site thoroughly. The results of this investigation will help determine the exact construction methods which are to be employed, the required thickness of the soil that is to be frozen, as well as the amount of refrigeration that will be required.

The first step in ground freezing is the insertion of freeze pipes into the ground on a circle which will ultimately be the center of the frozen earthen wall. Pipes 39 and 41 which are alternately long and short, as illustrated in FIG. 8, are preferably employed, with the long pipes 39 extending into the ground about 10–20 percent deeper than the bottom of the ultimate excavated hole. The short pipes 41 extend into the ground approximately 20 feet. The staggered arrangement of pipes provides a greater transfer surface and hence cooling capacity near the ground level where the largest amount of heat must be removed from the soil. In order to permit close control of the rate of freezing, two separate systems 43 and 45 for circulating refrigerant through the pipes are shown. The first system 43 is connected to the long pipes 39 through a manifold 44 and the second system 45 is connected to the short pipes 41 through a second manifold 46. The advantage of this arrangement derives from the fact that at times during normal tank operation heat leak from the ground into the insulated tank is not sufficient to maintain the frozen wall at the desired thickness. When this occurs, it is only necessary to pass refrigerant through the short pipes 41 since it is from the ground surface that the heat leak into the tank is the greatest.

As shown in FIG. 2, the long freeze pipes 39 are comprised of coaxial pipes 39a and 39b, and the manifold 44 is comprised of an inlet manifold 44a and a return manifold 44b. Refrigerant is circulated from the cooling unit 43 down through the inside freeze pipes 39a, up through the outside freeze pipes 39b and back to the cooling unit 43 through the return manifold 44b. The short pipes 41 and their associated manifold 46 are similarly constructed.

At the same time that the freeze pipes 39 and 41 are installed, several rows of temperature sensors 47, preferably of the type which produce an electrical indication of temperature on a pair of wires, are also inserted into the ground on radii extending out from the tank. The sensors may be contained in pipes (not shown), sunk into the earth to the same length as the long freeze pipes 39, and containing temperature sensors throughout their length. The wires of the sensors will, of course, be brought up through the pipes for connection to suitable controls or indicators. By sensing and monitoring the ground temperatures with the temperature sensors 49, the progress of ground freezing may be monitored and the time when excavation may begin can be determined. The temperature sensors 49 in combination with additional sensors 49 and 50 which are inserted inside the excavation 13 and also beneath its floor also serve to monitor the temperature of the earth surrounding the excavation during operation of the tank, as will be explained in greater detail hereinafter.

After the walls have been frozen to the desired thickness, excavation of the unfrozen center of the frozen ring by any of several known methods may begin. After excavation has progressed to a depth which will represent the bottom of the concrete ring 25, the latter is installed. The ring 25 contains reinforcing steel rods whose number and thickness will depend upon the diameter of the opening and upon the loads which the ring is to carry. The necessary calculations for determining the number, thickness and distribution of the reinforcing steel rods are well known in the civil engineering art and will not be described herein. It might be noted that, before the concrete ring 25 is poured, it is desirable that some portion of the frozen earth be chipped out in order that the concrete may be poured directly against the frozen ground to eliminate the possibility of ice lens formation.

After the concrete ring 25 has been installed, the unfrozen earth within is excavated to a depth which is several feet greater than that ultimately required. In the over-excavated portion at the bottom a heat exchanger 51 consisting of a series of connected pipes is installed. The heat exchanger 51 is connected to the manifold 44 which serves the long pipes 39. Additional temperature sensors 49 and 50 are placed along the bottom of the opening and along its side. After the heat exchanger 51 and the additional temperature probes 49 have been installed on the bottom of the opening 13, they are covered with a layer of sand 52 to a depth of several feet, usually less than four. Refrigerant is then pumped through the heat exchanger 51 until a bottom which is typically four feet thick is frozen.

The installation of the tank may now begin. First, the wall of the opening 13 is smoothed, preferably by spraying water upon it which freezes and produces a smooth surface. To further insure that no damage will

be done to the outer liner 23, padding is installed all around the opening over its wall and over its floor. This may be done by fiberglass mats 53 in the form of vertically running strips attached to the wall of the opening and layed over its floor, as shown in FIGS. 3 and 6. After the mats 53, which should be at least an inch thick, have been installed, the outer liner 23 is lowered into the opening. Preferably, it will be prefabricated to have a shape which conforms to the shape of the opening 13 and to have a size which is slightly larger than the opening. The latter will insure that when the outer liner 23 is put in place it will be slightly wrinkled so as to preclude the possibility of its being placed in tension when the tank is filled.

The outer liner 23 should be made of a cryogenically stable material. One which is believed will be found suitable includes at least one multilayer laminate having layers of aluminum and polyester. At its top the outer liner 23 is provided with a radially extending flange 23a by which it is anchored to the concrete ring 25. For this purpose a plurality of bolts 55 are anchored around the periphery of the concrete ring 25 and the rim 23a is fastened upon these bolts. FIGS. 5 and 5a show a suitable arrangement wherein the bolts 55 are distributed around the periphery of the concrete ring in a channel 58. A sealant paste is first applied in a layer 60 to the bottom of the channel 58 around the bolts 55, and the outer liner flange 23a is placed on top of the sealant layer 60. At subsequent stages of construction the extreme portions of the screening 61 and of the inner liner 17 are also extended into the channel 58, with additional layers 62 and 64 of sealant being applied under each of them. Finally, the entire sandwich structure thus formed is clamped by means of a series of arcuate retaining strips 56 made of a durable cryogenically stable material. The strips 56 will be typically several feet long and will be predrilled to mate with approximately six bolts 55 for each strip, each bolt receiving a respective nut 66 to secure the strips 56 thereon.

Having installed the outer liner 23, the thermal insulation may now be installed upon the floor of the opening on top of the liner. In accordance with a feature of the invention, the insulation is in the form of pillows 21 wherein particulated insulation is packed in bags 57 made of a cryogenically stable, porous material. The material needs to be cryogenically stable since at least some of the bags will be exposed to the cryogenic temperatures of the liquid stored within the tank. The advantage of making the bags out of porous material is that this allows trapped air to escape from within the bags when the tank is filled. Perlite has been found to be suitable for the insulating material.

The number of layers of insulating pillows 21 are a matter of choice, three being shown in the drawings.

Once the floor of the opening has been covered with the desired number of layers of bagged thermal insulation, the insulating of the wall of the opening 13 within the outer liner 23 may begin. The use of insulating pillows 21 comprised of bagged Perlite is again preferred. The insulating of the wall of the opening is best achieved by first stacking insulating pillows 21 along the wall of the opening 13 to a moderate height such as for example 10 feet. To prevent the inner liner 17 from having a sharp corner and thereby to reduce the

chances of rupture when the tank is filled it is desirable at this point to install all around the bottom corner of the opening 13 next to the pillows 21 a series of triangularly cross-sectioned corner pillows 65 which may be comprised of the same materials as those used for the pillows 21.

Means are next installed to help retain the insulating pillows 21 which have been stacked next to the wall of the opening. In the exemplary embodiment illustrated in FIGS. 1 and 2, these means comprise a screening 61 combined with a series of expandable retaining bands 59. As best seen in FIG. 1, the screening 61 is made up of a plurality of screen strips 63 which are laid upon the floor of the opening, with their edges slightly overlapping to make for a continuous, pie-shaped piece of screening. The screen strips 63 are brought up next to the stacked pillows along the wall of the opening 13. To hold the screen strips 63 in place against the bags 21 a first retaining band 59 is installed and is expanded sufficiently to hold it, and the screen strips 63 in place. The retaining bands are provided for this purpose with one or more ratcheted expanding joints 60 of conventional construction which permit the retaining bands to expand, both during installation and subsequently, when the bands are further expanded typically by several feet, by the pressure exerted upon them when the storage tank is filled. The retaining bands will generally be of a semitubular shape, that is their cross-section would be arcuate, to obtain structural strength and to present a smooth surface without abrupt corners to the inner liner 17. The ratcheted expanding joints 60 would be in the hollow of the retaining bands and would have no contact with inner liner 17. The ratcheting is so arranged that the retaining bands 59 can only expand and cannot contract even when the pressure which had caused them to expand in the first place is removed, as by emptying of the storage tank.

The screen strips 63 overlap not only along the floor of the opening, but also along the wall so that a generally cylindrical screening is formed inside the insulating pillows 21 along the wall of the opening. In some instances it may be advisable to sandwich a lubricant, such as a strip of polyester, between the overlapping edges of adjacent screen strip 63 so as to allow them to slide rather than tearing in response to the pressure of liquid within the tank.

Once the screen strips 63 have been fastened under the first retaining band 59, more insulating pillows 21 may be piled on top of those which had been initially placed next to the wall. As shown in FIG. 2 when the pillows 21 have been stacked along the wall to an additional height, approximately the same as the initial height of pillows stacked there, another retaining band 59 is installed and the screen strips 63 are raised all around the wall of insulation and fastened under the second retaining band 59. This process continues, with additional pillows being piled on top of those stacked previously and with successive retaining bands 59 being installed, each time raising the screen strips just above the last retaining band so installed. The process continues until the wall of insulating pillows and the screening 61 inside it reaches the top of the opening 13. At this point the screen strips 63 are brought over on top of the pillows 21 and are fastened upon the concrete ring 25 in the manner explained previously with reference to FIG. 5a.

The next step is to install the inner liner 17 which in the preferred embodiment has the same bucket shape as the outer liner 23, but which of course is made to be smaller. The inner liner 17 is provided with a radially extending flange 17a at its top and the flange is fastened on top of the outer liner flange 23a by means of the bolts 55 and the washers 56 (FIG. 5a).

As an aid in the proper installation of the inner liner 17 the air between the inner and outer liners 17 and 23 is exhausted through an opening 69. The resulting vacuum inside the space formed by the two liners 17 and 23 causes the inner liner 17 to press against the screening 61 so that both the screening and the inner liner conform generally to the shape of the pillows 21 which are stacked against the wall of the opening. The inner liner 17 is designed with a waffled surface configuration to be slightly larger than the space inside the insulating pillows 21.

It may be seen at this point that the screening 61 serves a dual purpose. As noted earlier, it serves to hold the insulating pillows 21 flat against the wall of the opening in combination with the retaining rings 59. The screening 61 also serves, however, as a reinforcement for the inner liner 17. Thus where the liner bridges a gap between adjacent insulating pillows, and particularly where such a bag collapses under the weight of cryogenic liquid within the inner liner 17, the screening keeps the inner liner from ballooning into the resulting space. For this reason, the screening is preferably made of some cryogenically stable material having good structural strength. It may be, for example, made of either fiberglass screening, aluminum screening, or stainless steel screening. Tests have proven that the strength of the laminate which makes up the inner liner 17 can be substantially increased by use of the screening 61. It should be understood that the concept of a storage tank wherein screening and retaining bands are used to support the insulating wall pillows 21 and to reinforce the inner liner 17 is not claimed herein since it is the joint invention of Joseph A. Connell, Anthony J. Baranyi and Paul V. Laylander. Instead, it is claimed in a separate application entitled Cryogenic Storage Tank Improvements, Ser. No. 80,117 being filed Oct. 12, 1970 by the said inventors. It should also be understood that, while the use of screening and retaining bands to retain the insulating wall pillows 21 has significant advantages, their use is not essential to construct a storage tank incorporating the basic concepts of the present invention. Other means for retaining the insulating pillows may occur to those skilled in the art and these means may or may not serve also to reinforce the inner liner 17.

With the inner liner 17 in place the next step is to install the diaphragm 19. The diaphragm preferably is made of the same laminate as the liners 17 and 23 and is sufficiently large so that it extends past their flanges 17a and 23a. It is provided with a series of openings about its periphery which fit around a corresponding plurality of bolts 67. By means of retaining strips 70 of the same type as the retaining strips 56 used for the liners 17 and 23 the edges of the diaphragm 19 are sealed to the top surface of the concrete ring 25 so that the ring provides a seal between the double walled insulating bucket formed by the inner and outer liners 17 and 23 on the one hand and the diaphragm 19 on the other hand.

Preferably, a fiberglass cushion 71 about one inch thick (see FIG. 4) is laid on top of the diaphragm 19 to prevent it from rubbing against the net 29 which is next in the order of installation. Specifically, a net 29 of steel cables is stretched across the concrete ring 25. In the exemplary embodiment disclosed particularly in FIGS. 1 and 5, the net 29 is comprised of an outer steel I-beam ring 72, an inner steel ring 74, and a plurality of steel cables 73 stretched radially between them. The entire net 29 can be assembled away from the tank and lowered in one piece by a crane to rest upon the horizontal ledge of the concrete ring 25, where it would then be bolted, to prevent it from rising thereafter. Thermal insulation 76 in loose form is installed around the edge of the net 29 to prevent heat leaks between the ceiling insulation 31 and the wall insulation 21. Suitable tensioning devices 79 are usually provided near the end of the cables to give them a desired catenary. A layer of screening 81 is installed on top of the net 29 to provide a continuous floor upon which the thermal insulating ceiling can be stacked. To provide a moisture-impervious protective layer for the thermal ceiling insulation 31, a liner 85 which may be of the same construction as the liners 17 and 23 is next installed on top of the screening 79. Then, before the thermal insulation 31 is installed on top of the liner 85, a flange 87 is first formed through the liner 85, the screening 81, the fiberglass padding 71, and the diaphragm 19 below by cutting a hole 88 through them in order to accommodate the casing of the submersible pump 37.

Under the hole 88 a gasket 89 is placed and immediately on top of the hole opposite the gasket 89 a double-flanged collar 91 is laid. The gasket 89 and the collar 91 are fastened together by a set of bolts 93, thereby forming a vapor sealing flange 87 and sandwiching between them the liner 85 and the diaphragm 19. The next step is to lower the submersible pump system 37 through the flange 87 just formed. A suitable such pumping system is manufactured by the Carter Pump Company of Costa Mesa, California and is described in U.S. Pat. No. 3,369,715 issued to J. C. Carter. Since the pumping system is commercially available, it will not be described herein in detail. Suffice it to say that it includes a casing 95 having a bottom portion 95a and a top portion 95b having abutting flanges 99 and 100 which are clamped and sealed together.

The initial part in installing the pumping system 37 is to lower the casing 95 through the flange 87 by means of a crane. The casing 95 is lowered to a depth sufficient to bring its bottom close to but not in contact with the bottom of the storage tank. It is then fixed in place upon the support structure 35, suitable brackets 102 being provided on the casing 95 for this purpose, and its flanges 99 and 100 are bolted to the top flange of the ceiling collar 91. Next, a submersible, electrically powered pump 105 is lowered in place to the bottom of the casing 95 to rest on top of a foot valve assembly 107 which automatically opens in response to the pump 105 being seated thereon. Electric power is supplied to the pump 105 through an electric cable 109 fed from a conduit 108. By means of a connecting member 103, which may be either a pipe or a cable suspended from a cover plate 101 at the top of the casing 95, the pump

105 may be both lowered into place and subsequently lifted and removed from the casing 95 for repairs without unduly disrupting the operation of the storage tank. For this purpose the connecting member 103 is suspended from the cover plate 101 by means of a hand crank 104 which, when turned, is operative to lift or lower the pump 105. The hand crank 104 is used only to lift the pump 105 sufficiently to close the valve assembly 107. When it is desired to entirely remove the pump 105 from the casing 95, the cover plate 101 is removed and other means, such as a crane are used to pull the pump 105 from the casing.

As described in greater detail in the referenced Carter patent, cryogenic fluid is pumped out of the storage tank through an inlet and outlet pipe flange 110 which extends from the upper casing portion 95b.

At the same time that the pump casing 95 is installed, there is also installed in the ceiling of the tank a fill and vent assembly 113 comprised of a flanged, vent pipe 114 and a liquid fill pipe 116 supported within the vent pipe. This may be accomplished in a manner similar to the installation of the casing 95. In particular, an opening 112 is cut through the ceiling material and receives a gasket 111 and a double flanged collar 118 which are fastened together by a set of bolts 117. The vent pipe 114 extends up through the ceiling structure of the tank and is rigidly held in place by brackets 120 bolted to the support structure 35. The liquid fill pipe 116 also extends through the ceiling structure and has at its bottom a splash plate 122 to disperse the cryogenic fluid being fed therethrough.

Once the pump assembly 37 and the fill and vent assembly 113 have been installed through the ceiling structure, the thermal ceiling insulation may be laid. This thermal insulation may be in the same form as that used for insulating the floor and walls of the storage tank and is therefore shown in FIGS. 2 and 7 as several layers of thermally insulating pillows 31. The insulating pillows 31 are laid over the entire ceiling on top of the liner 85 and are preferably packed to the edge of the concrete ring 25 as shown in FIG. 5. A second liner 121, which may be of the same material as the bottom ceiling liner 85 is then installed over the ceiling insulating pillows 119. The ceiling screening 81, and the ceiling liners 85 and 121 are anchored at their peripheries in a groove 82 which extends all around the top of the concrete ring 25. As shown in FIG. 5, the manner of attachment is similar to that used for the tank diaphragm 19. In particular, the screening 81 and the liners 85 and 121 are sandwiched together in the groove 82, with a sealant being applied under each of them, and they are clamped in the groove 82 by means of long arcuate strips 83 fastened down by bolts 84 and nuts 86 distributed along the groove. Additional vapor seals 124 are provided subsequently where the casing 95 and the pipe 113 penetrate the upper liner 121 and the ceiling 33. The two liners 85 and 121 together form a moisture-impervious barrier which fully encloses the ceiling insulating pillows 119. The space between the liners will be purged with inert gas.

To protect the ceiling 27 from damage caused by the elements, it is advisable to install a protective roof 33. This structure may be made of a flexible, airtight commercially available material, such as vinyl coated nylon fastened at its edges to the outer periphery of the

concrete ring by a set of bolts 123 and washers 125. The protective roof 33 may be inert gas supported by maintaining the pressure in the space 127 below it at slightly above atmospheric.

Prior to filling the vessel with cryogenic fluid, a purging of the inner vessel and insulated annular space between outer and inner liners 23 and 17 with inerting gas is accomplished by introducing inerting gas, such as nitrogen, into the inner vessel area first, and then into the annulus through the inlet 69, maintaining a higher pressure in the vessel than in the annulus to avoid displacement of the inner liner 17 from the insulated wall.

The filling of the tank may now begin. It will usually be done through both the fill pipe 116 and the pump housing 95. For this purpose, the pipe flange 110 of the housing 95 is connected to a source of cryogenic fluid as is the fill pipe 116. By means of suitable external pumps, cryogenic fluid will then be fed through the pipes 110 and 116. The feeding of the cryogenic fluid through the fill pipe 116 has the advantage that the cryogenic fluid is dispersed by means of the splash plate 122 near the top of the tank, thus serving to condense some of the rising flash and vapor which is always generated when cryogenic fluids are transferred. At subsequent times when the level of the cryogenic fluid in the tank has diminished, additional cryogenic fluid may be supplied through the fill pipe 116. This may be done either while the submerged pump is inoperative or at the same time that cryogenic fluid is being withdrawn from the tank by means of the pump 105 through the pipe 110.

To summarize, what has been described in some detail has been a preferred method of constructing an underground storage tank for cryogenic fluid and a storage tank constructed by such a method. It will be appreciated that a storage tank such as that described has significant advantages over storage tanks which have been constructed previously. Thus, for example, the use of thermal insulation packed in bags to form pillows solves the problem previously encountered by thermal insulation which had been implanted in the form of rigid bricks.

Another feature of the storage tank described herein was seen to be the use of sufficient insulation to reduce the heat leak from the surrounding earth into the storage tank to a low enough level so as to prevent the thickness of the frozen wall from expanding out of control. Instead, the storage tank of the present invention is so designed as to require additional cooling by means of the freeze pipes which surround the storage tank in order to maintain the frozen earthen wall and floor which surround the storage tank at a desired thickness. In keeping with this aspect of the invention, as mentioned previously, a cooling system which preferably is comprised of a pair of cooling units 43 and 45 is provided. As mentioned previously, and as shown in addition in FIG. 9, the outputs of the cooling units 43 and 45 are connected to the long pipes 39 and to the short pipes 41 respectively and the cooling units are operated in response to signals received from the wall and floor temperature sensors 47 and 49, so as to vary the rate at which they remove heat from the refrigerant being circulated through the pipes.

The manner in which the cooling units 43 and 45 are controlled in response to the detected floor and wall

temperatures may be varied. Thus, the temperature sensors 47 and 49 may be connected through respective wires to a common instrument panel near the cooling units 43 and 45 and a human operator can increase or reduce the output of the cooling units 43 and 45 as deemed by him necessary to maintain the frozen earthen wall and floor of the storage tank at a desired uniform thickness.

It is anticipated that the greatest heat leak into the tank will occur near the surface so that in most instances, once the earthen walls of the tank have been frozen, it will only be necessary to operate the small cooling unit 45 and its associated short freeze pipes 41.

If it is desired to eliminate the human operator, the cooling system may be made automatic by interposing a control unit 127 between the temperature sensors 47 and 49 and the cooling units 43 and 45. The design of a suitable control unit is well within the skill of persons acquainted with the art of automatic temperature control and will not be described herein. It will be sufficient to understand that the electrical outputs of the temperature sensors 47 and 49 will be applied to the control unit 127 which in turn will apply suitable control signals, either electrical or mechanical, to the cooling units 43 and 45 so as to maintain the thickness of the frozen earthen wall and floor of the storage tank at a predetermined level.

What has been described herein is a storage tank which can hold a very large quantity of cryogenic fluid, such as liquid natural gas, at a considerably lower cost than has been heretofore possible. This has been achieved through the combination of a number of structural features, such as the provision of a permanently frozen opening in the earth's surface whose walls are maintained at a constant thickness to prevent frost heaving, through the packing of thermal insulation in cryogenically stable porous bags, and through the sealing of such bags in a double walled liner to form in essence an insulating bucket inside the frozen opening. These and other features of the invention are defined in the claims which follow.

What is claimed is:

1. In an underground storage tank for liquefied gas comprising:

- a. an opening in the earth's surface;
- b. a moisture-impervious liner covering the floor and walls of said opening;
- c. a resilient, collapsible, liquid and gas impervious container inside said lined opening;
- d. a layer of thermal insulation distributed between said container and said liner, said thermal insulation being sufficient to avoid frost heave of said storage tank due to heat loss from said floor and walls into said liquefied gas;
- e. a thermally insulated ceiling covering the top of said opening; and
- f. means for maintaining the earthen wall and floor of said opening frozen to a controlled thickness during use by selectively cooling said floor and walls.

2. The storage tank of claim 1 characterized further in that said container is comprised of at least one multilayer laminate having layers of aluminum and polyester.

3. The storage tank of claim 1 characterized further in that:

- a. a concrete ring surrounds the lip of said opening; and
- b. said liner is suspended from said ring.
- 4. The storage tank of claim 1 characterized further in that said insulation is packed in bags made of a cryogenically stable, porous material, and said bags are stacked upon the floor and along the wall of said opening.
- 5. The storage tank of claim 1 characterized further by means for holding upright those bags of insulation which are stacked along the wall of said openings.
- 6. The storage tank of claim 1 characterized further by a shelf of compressible material extending along the bottom of said wall on the insulated floor of said opening to form an indentation in said container which fills out under the weight of said liquified gas in said container by partially compressing said shelf.
- 7. The storage tank of claim 1 characterized further in that said thermally insulated ceiling is comprised of:
 - a. two moisture-impervious liners sealed at their edges and extending across the top of said opening; and
 - b. thermal insulation sandwiched between said two layers.
- 8. The storage tank of claim 1 characterized further in that said means for maintaining the earthen wall and floor of said opening frozen to a desired thickness are comprised of:
 - a. freeze pipes permanently installed in the floor and wall of said opening;
 - b. means for circulating a heat conducting liquid through said freeze pipes; and
 - c. means for removing heat from said circulated liquid
 - 1. prior to the operation of said storage tank to freeze said floor and walls, and
 - 2. during the operation of said storage tank to maintain said frozen floor and walls at a desired thickness.
- 9. The storage tank of claim 8 characterized further by
 - a. temperature probes placed in the earth around said opening for indicating the condition of said floor and wall; and
 - b. means responsive to said temperature probes for controlling the rate at which heat is removed from said liquid so as to maintain the frozen floor and wall of said opening at a desired thickness.
- 10. The storage tank of claim 1 characterized further in that said container is comprised of:
 - a. a laminate body in the shape of an inverted hat having a radially extending flange at its top; and
 - b. a laminate disk-shaped lid sized to reach substantially to the outer perimeter of said flange.
- 11. The storage tank of claim 10 characterized further in that:
 - a. a concrete ring surrounds the lip of said opening; and
 - b. the body-flange and lid of said container are both anchored upon said ring.
- 12. An underground storage tank for liquified gas comprising:
 - a. an opening in the earth's surface, having an earthen floor and wall kept frozen during use by a cooling system having freeze pipes embedded in said floor and wall;

- b. a container conforming when filled to the shape of said opening;
- c. thermal insulation means distributed between said container and the floor and wall of said opening for limiting the heat loss from said floor and wall into said liquified gas to a sufficient extent to allow said cooling system to control the freezing of said earthen floor and wall; and
- d. a thermally insulated ceiling covering the top of said opening.
- 13. An underground storage tank for liquified gas comprising:
 - a. An opening in the earth's surface, having an earthen floor and wall kept frozen during use by a cooling system having freeze pipes embedded in said floor and wall;
 - b. A container conforming when filled to the shape of said opening said container comprised of:
 - a. a bucket-shaped laminate body having a radially extending flange at its top; and
 - b. a laminate disk-shaped lid sized to reach substantially to the outer perimeter of said flange and bonded thereto;
 - c. thermal insulation means distributed between said container and the floor and wall of said opening for limiting the heat loss from said floor and wall into said liquified gas to a sufficient extent to allow said cooling system to control the freezing of said earthen floor and wall.
- 14. An underground storage tank for liquified gas comprising:
 - a. An opening in the earth's surface, having an earthen floor and wall kept frozen during use by a cooling system having freeze pipes embedded in said floor and wall;
 - b. A concrete ring surrounding the lip of said opening;
 - c. A container conforming when filled to the shape of said opening; said container comprised of:
 - 1. a bucket-shaped laminate body having a radially extending flange at its top, said body attached to and supported by said concrete ring; and
 - 2. a laminate disk-shaped lid sized to reach substantially the outer perimeter of said flange said lid attached to and supported by said concrete ring.
- 15. For use in storing liquified gas in a bucket-shaped opening in the earth's surface a thermally insulated container comprising:
 - a. a sealed, double walled, liquid and gas impervious bucket-shaped liner covering the floor and wall of said opening, and having a rim at its top;
 - b. thermal insulation packed in porous bags and distributed in a continuous layer between the inner and outer walls of said liner;
 - c. a liquid and gas impervious diaphragm stretched across the mouth of said opening and sealed to the rim of said liner; and
 - d. thermal insulation distributed in a continuous layer above said diaphragm.
- 16. For use in storing liquified gas in a bucket-shaped opening in the earth's surface a thermally insulated container comprising:
 - a. a sealed, double walled, liquid and gas impervious bucket-shaped liner covering the floor and wall of said opening, and having a rim at its top;

15

- b. thermal insulation packed in porous bags and distributed in a continuous layer between the inner and outer walls of said liner;
- c. a reinforcing screen surrounding the inner wall of said liner;
- d. a liquid and gas impervious diaphragm stretched

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- across the mouth of said opening and sealed to the rim of said liner; and
- e. thermal insulation distributed in a continuous layer above said diaphragm.

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