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Connell et al.

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[45] **Jan. 2, 1973**

[54] CRYOGENIC STORAGE TANK IMPROVEMENTS

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[22] Filed: **Oct. 12, 1970**

[21] Appl. No.: **80,117**

[52] **U.S. Cl.** **62/45**, 61/.5, 62/260

[51] **Int. Cl.**.....**F17c 1/00**

[58] **Field of Search** 61/.5; 62/45

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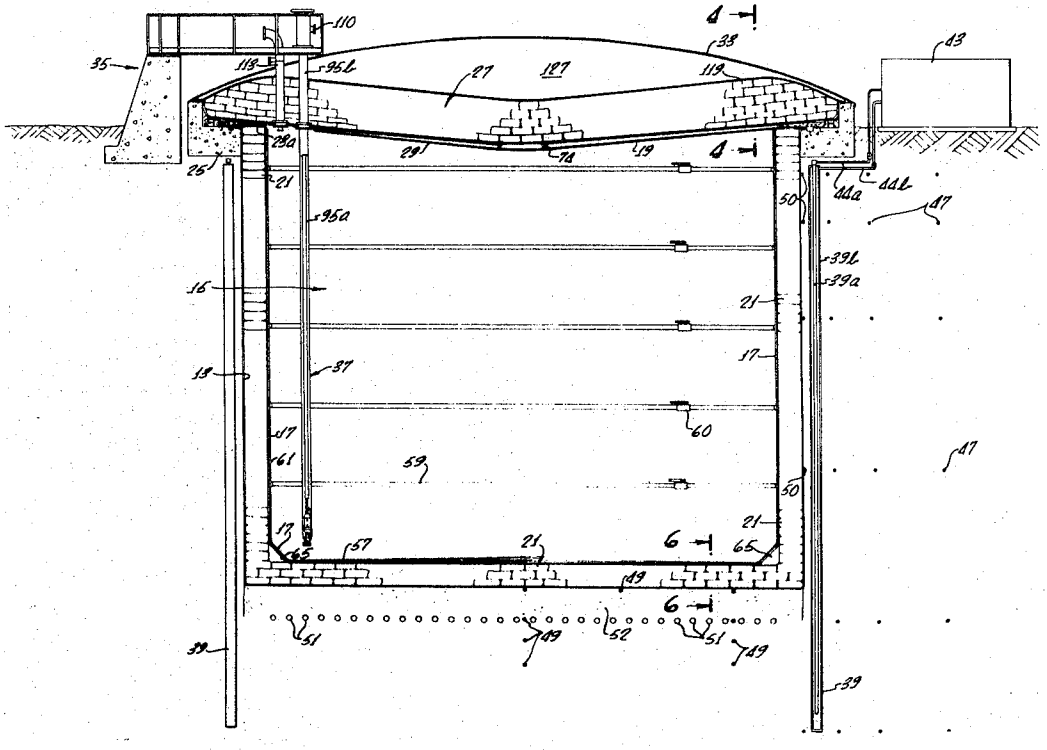
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[57] **ABSTRACT**

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.

7 Claims, 9 Drawing Figures



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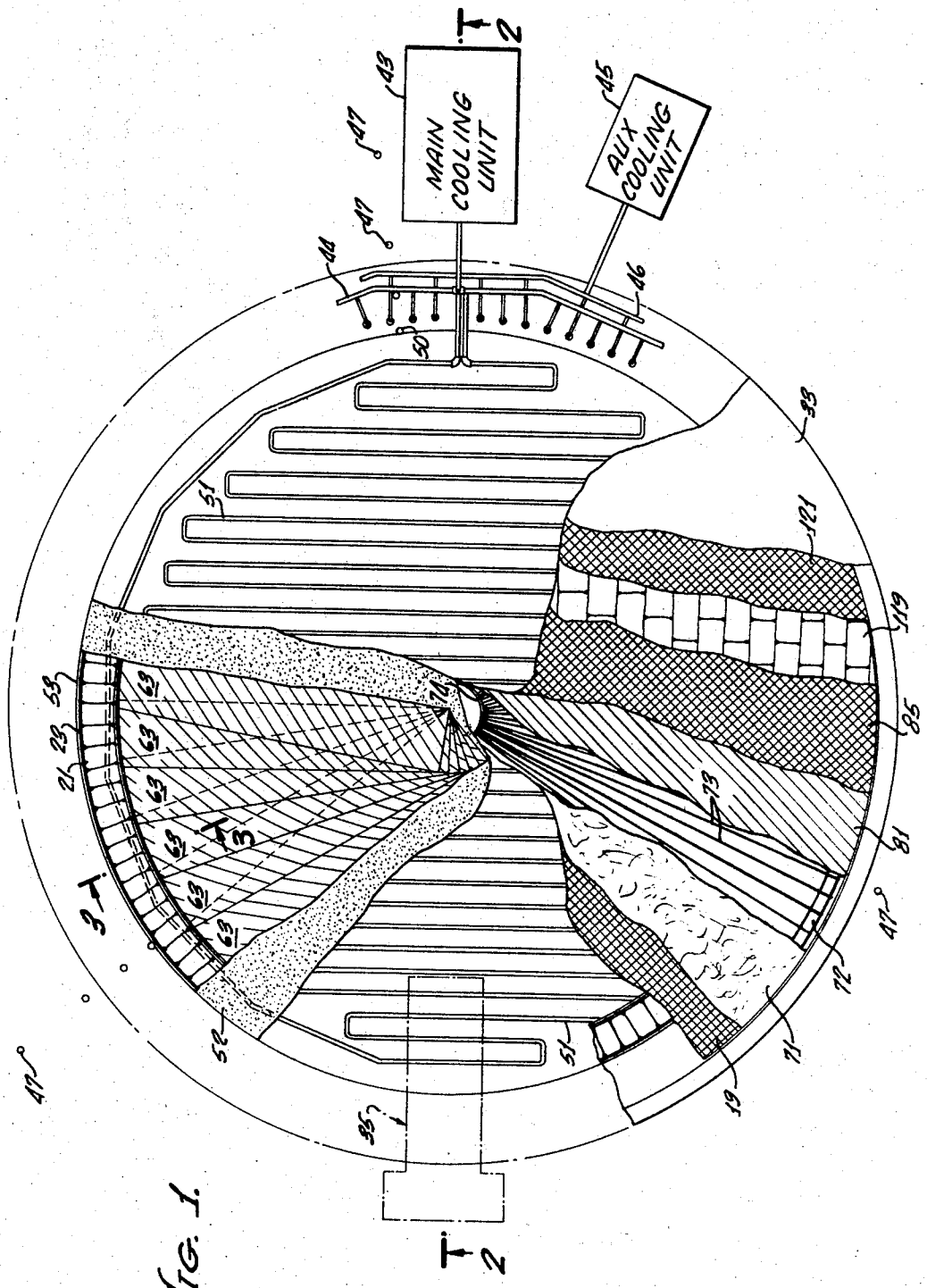


FIG. 1.

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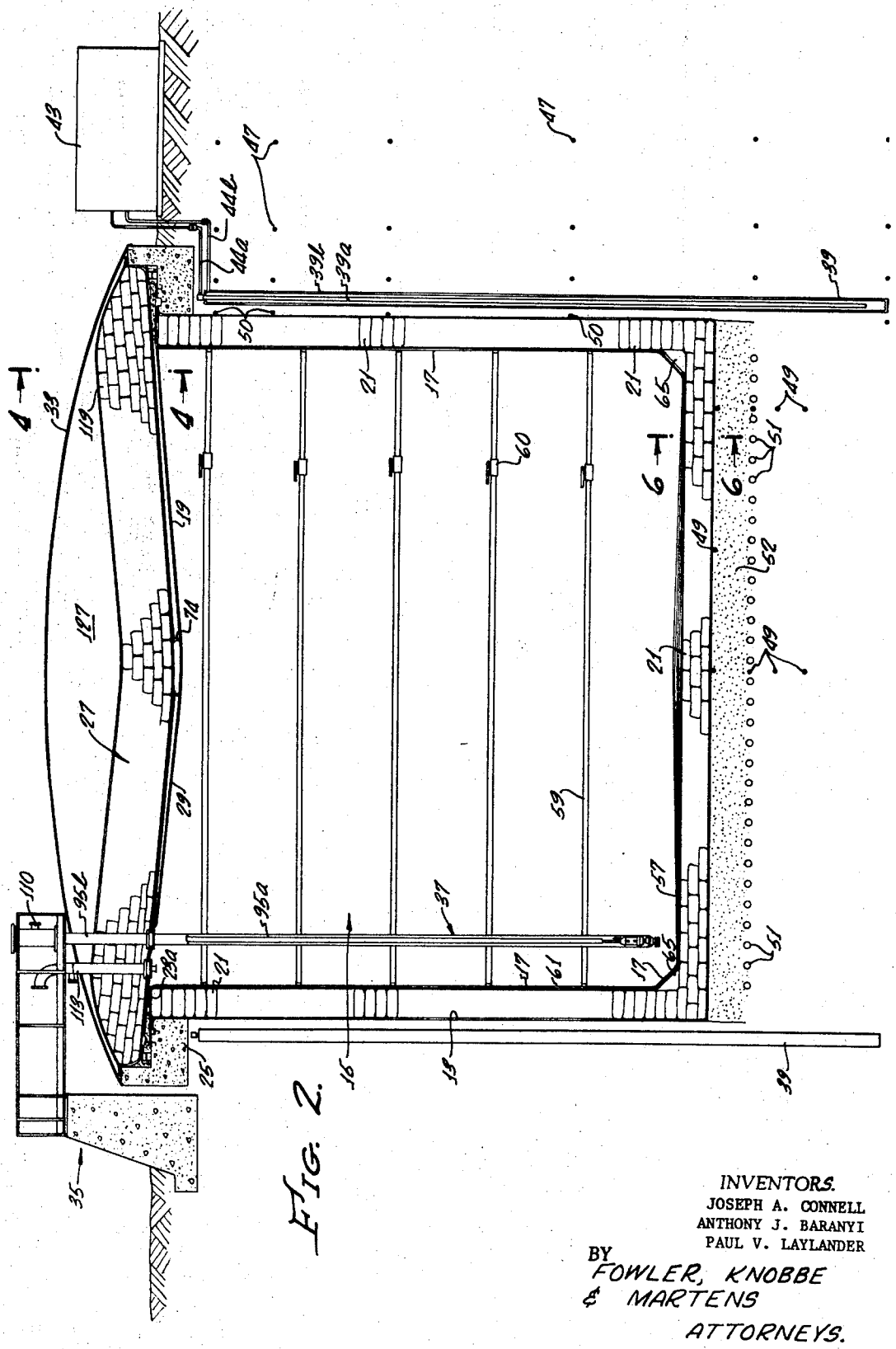


FIG. 2.

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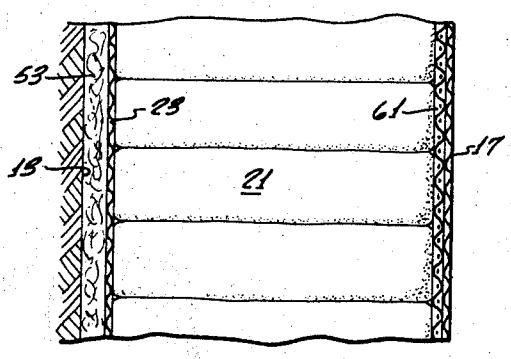


FIG. 3.

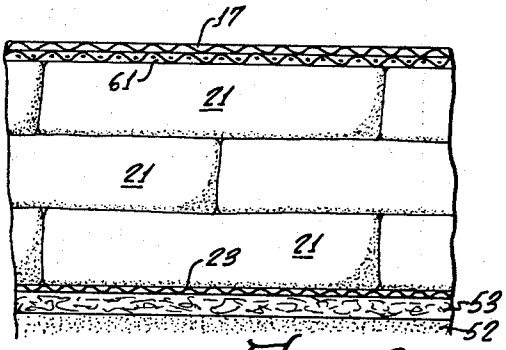


FIG. 6.

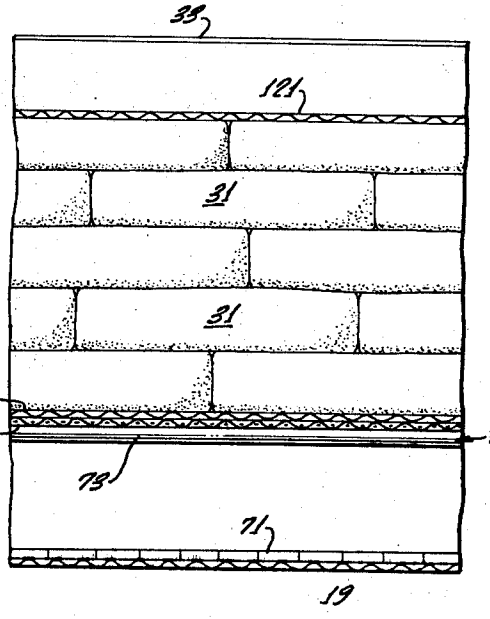
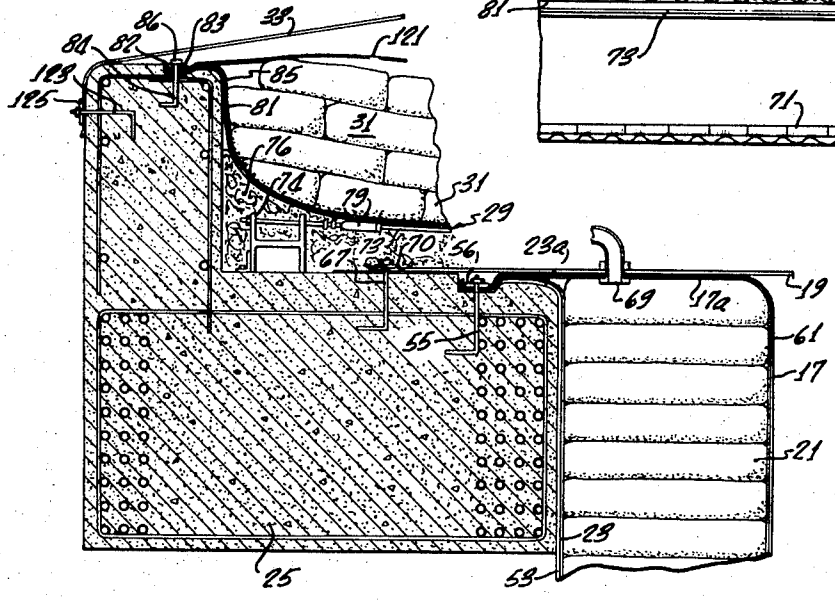


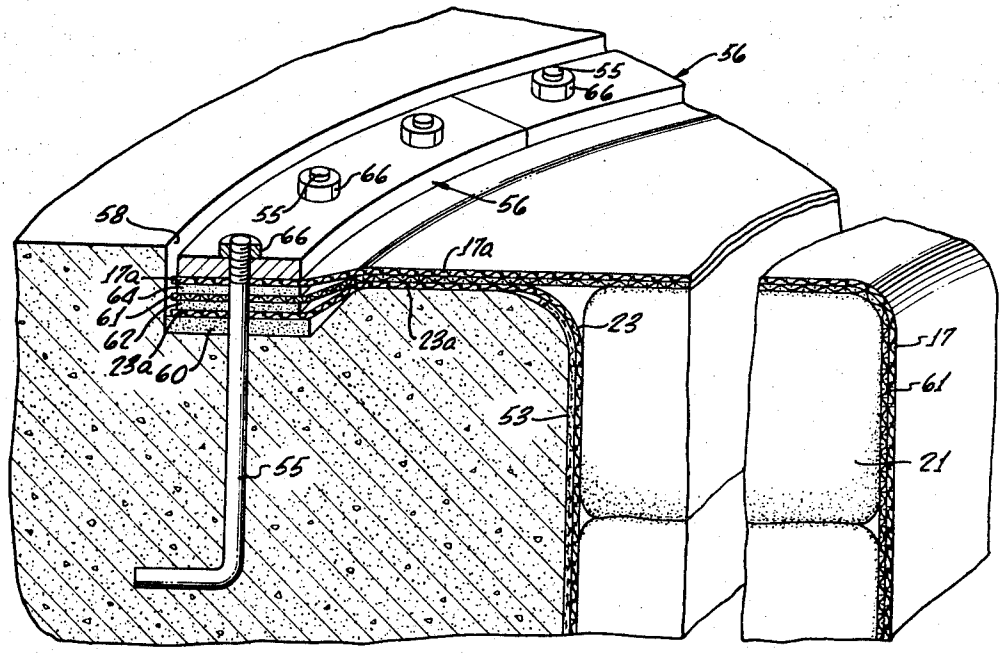
FIG. 4.

FIG. 5.



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FIG. 5a.



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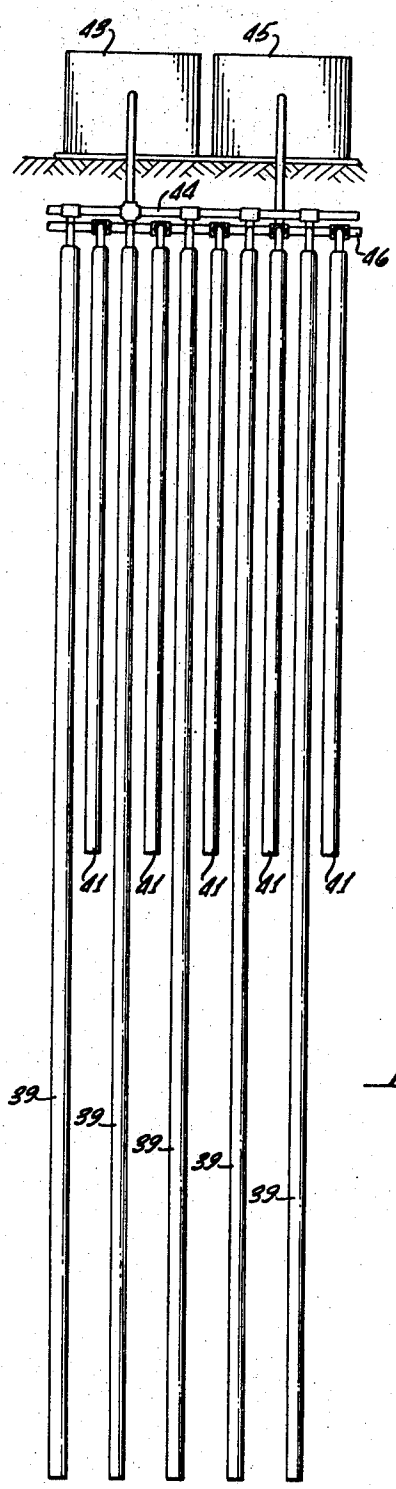


FIG. 8.

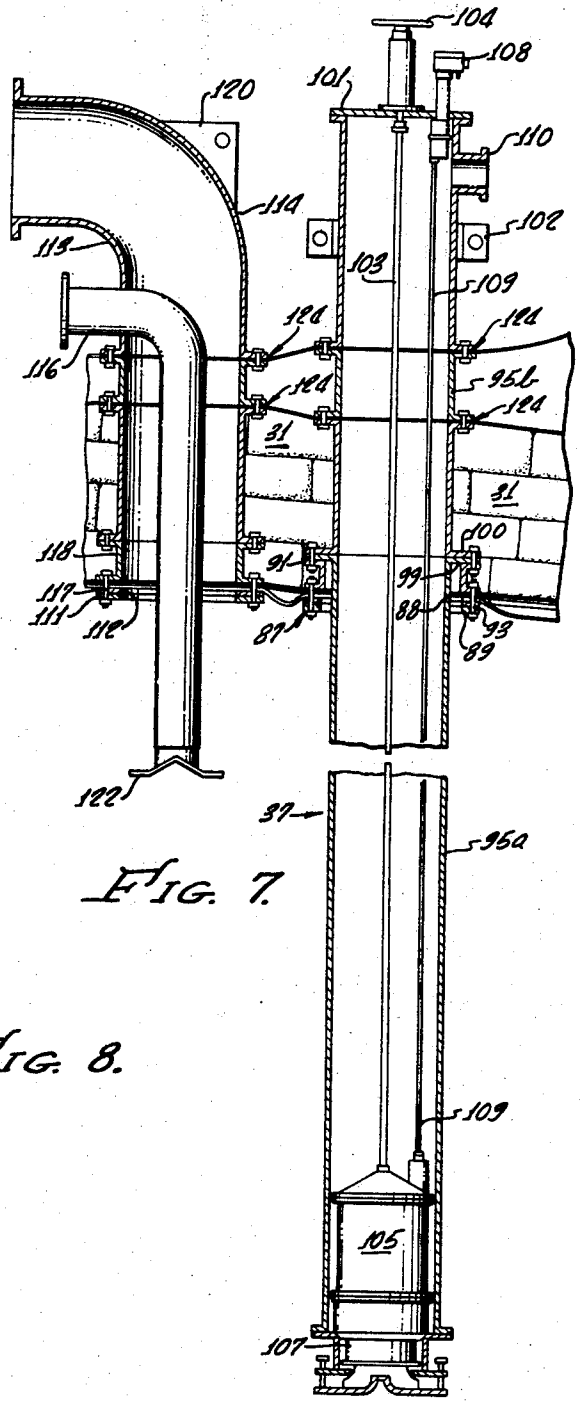


FIG. 7.

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CRYOGENIC STORAGE TANK IMPROVEMENTS

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.

More particularly, the present invention is directed to certain structural features of an underground storage tank which was broadly conceived by Joseph A. Connell and Anthony J. Baranyi and which is described and claimed in a patent application entitled METHOD AND MEANS FOR THE UNDERGROUND STORAGE OF LIQUIFIED GAS Ser. No. 99,980 filed by the above joint inventors on Oct. 12, 1970. The aforesaid underground storage tank is constructed by first excavating a generally bucket-shaped opening in the earth's surface and placing two bucket-shaped liners, one within the other, into the opening. Between the two liners thermal insulation packed in bags is distributed along the floor and wall of the opening. The two liners have radially extending flanges which are sealed to one another so as to form, together with the thermal insulation between them, a double walled, moisture-impervious insulating bucket within the opening in the earth. A diaphragm caps the top of the insulating bucket and forms with it a container for receiving cryogenic liquid such as liquid natural gas. A thermally insulating ceiling is suspended above the diaphragm in order to form a completely thermally insulated container.

The present invention lies in certain methods and structural features for constructing an underground storage tank of the above type. Thus, in accordance with one of these features, a layer of padding is placed over the wall of the opening and the outer liner of the insulating bucket is installed within that layer, thereby protecting the outer liner from puncture by sharp projections on the wall of the earthen opening.

In accordance with another aspect of the present invention, a unique retaining structure is provided between the bags of insulation which are stacked along the wall of the opening and the inner liner. This retaining structure has a dual purpose. First, it serves to prevent the bags which are stacked along the wall of the opening inside the outer liner from falling down. That this would otherwise be a problem will be appreciated when it is considered that a typical height for the wall of the opening, and hence for the stacked bags along that wall, is of the order of 60 feet. In carrying out this feature of the invention, the insulating bags or pillows are stacked inside the outer liner to a height which is a fraction of the total height of the wall of the excavated opening.

A screening is then installed along the floor of the opening on top of the inner liner, is brought up inside the stacked insulating pillows and is held in place by means of an expandable cryogenically stable retaining ring. Once that ring is installed, the height of the stacked bags is increased by piling additional insulating pillows to an additional height approximately equal to the height of the first set of pillows thus installed. The screening is then extended further upward so as to cover the additionally stacked pillows and a second expandable retaining ring is put in place inside the screening near the top of the stacked pillows. This process continues, with the height of the pillows being successively increased along the wall of the opening and with the screening and additional retaining bands being installed all the way to the top of the opening.

With the insulating pillows all held securely in place, the inner liner is installed inside the retaining structure which also serves to reinforce that inner liner when it is filled with cryogenic liquid. This is particularly important because the insulating pillows are by their nature compressible. Moreover, they present to the inner liner a surface having gaps which the liner must bridge. Both of these characteristics tend to cause the inner liner to balloon outward under the weight of the liquid within. Thus, the retaining structure and particularly the screening serve not only to hold the insulating pillows in place but also serve the important function of lending additional strength to the inner liner to prevent it from being ruptured by the fluid which is stored within it.

In the storage tank which is described in the above-referenced patent application, there is described a concrete ring which is installed at the rim of the opening and which serves to support the inner and outer liners by means of a set of anchoring bolts distributed around its periphery. In accordance with the present invention, a lightweight supporting structure is mounted upon this concrete ring to support the thermally insulating ceiling which is required above the top of the underground container. In keeping with this feature of the invention, the supporting structure is in the form of a net comprised of steel cables stretched across the concrete ring. On top of the cables a cryogenically stable screening, of the same type used to maintain the bags in the opening upright, is laid. A liner, similar to those used for the insulating bucket, is then laid on top of the cryogenically stable screening and insulating pillows, again of the same type used between the inner and outer liners, are installed in several layers over the liner. A second liner is laid on top of the layers of insulating pillows and the top and bottom liners are sealed together at their edges so as to form a moisture-impervious enclosure or envelope for the thermally insulating pillows between them.

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. **5***a* 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; and

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.

In the detailed description which follows, an exemplary storage tank incorporating features of the present invention is described in detail. It should be kept in mind that several of the structural features as well as several of the construction methods described herein are the joint inventions of Joseph A. Connell and Anthony J. Baranyi, are not claimed in the present application, but are claimed instead in the above-referenced application of these joint inventors.

An underground storage tank incorporating features of the present invention is illustrated in FIGS. 1, 2, and 5. As best seen in FIGS. 1, 2, and 5, the exemplary storage 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 bags 31 packed with 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.

The storage tank 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 39*a* and 39*b*, and the manifold 44 is comprised of an inlet manifold 44*a* and a return manifold 44*b*.

Refrigerant is circulated from the cooling unit 43 down through the inside freeze pipes 39*a*, up through the outside freeze pipes 39*b* and back to the cooling unit 43 through the return manifold 44*b*. 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 47 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 explained in the related Joseph A. Connell and Anthony J. Baranyi application, one or both of the cooling systems 43 and 45 are kept running during the operation of the tank so as to keep the thickness of its frozen floor and wall within set limits, with the status of the floor and wall being determined by the sensors 49 and 50.

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 of 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 4. 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**, and in accordance with a feature of the present invention, padding is installed all around the opening over its wall and base. 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 bottom, 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 **23***a* 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 **23***a* is fastened upon these bolts. FIGS. **5** and **5***a* 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 **23***a* 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. The insulation is preferably 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 insulation 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 ten 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**, forming a curved radial side wall-to-base configuration.

In keeping with a principal feature of the present invention, 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**, and in further keeping with the present invention, 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 **59** will contract at cryogenic temperatures but this is provided for in the expandable ratcheting connections **60**. The retaining bands will generally be of a semi-tubular 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 strips **63** so as to allow them to slide relative to one another. In this way, the screening **61** is made capable of expanding under the pressure of liquid entering the tank. This is particularly important because the insulating pillows **21** are significantly compressed by the liquid, especially toward the bottom where they may be compressed by more than 6 inches.

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 **59** 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. **5***a*.

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 **17***a* at its top and the flange is fastened on top of the outer liner flange **23***a* by means of the bolts **55** and the washers **56**.

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** of the present invention 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**.

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 **17***a* and **23***a*. 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.

The provision at this point of a light yet strong, thermally insulating ceiling forms yet another feature of the present invention. 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 **73** to give them a desired catenary.

Before installing the net **29**, it is desirable first to lay a protective cushion **71**, such as one inch thick fiberglass on top of the diaphragm **19** to prevent it from rubbing against the net.

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 **95***a* and a top portion **95***b* 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 casting **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 **95***b*.

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 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 liners **85** and **121**, filled with bagged Perlite insulation, is maintained in an inerted gas atmosphere, such as nitrogen.

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 in 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**.

During the initial filling of the tank the lateral pressure of the liquid being exerted upon the wall of the inner liner **17** will cause that liner to expand, this being made possible by the presence of waffling distributed over its entire surface. The screening **61** will also expand by virtue of the sliding engagement of its individual strips **63**, as will the retaining bands **59** by virtue of its ratchet joints **60**. The principal reason for this expansion is the compressibility of the insulating pillows **21** which line the wall of the opening **13**.

In essence, therefore, the entire double walled insulating bucket, which is comprised of the liners **17** and **23** and of the pillows **21** between them, is compressible, with its inner wall being made expandable for this purpose. However, once the tank assumes its final configuration upon being filled, it will retain that configuration even if the liquid is withdrawn therefrom. This is partly because the insulating pillows **21** do not spring back to their original shape, but remain in their compressed form and partly because the retaining bands maintain their expanded dimension as a result of their one-way ratcheted joints. Thus, by use of compressible insulation and expandable inner wall construction in the tank, a liquid container is provided which can withstand very high liquid pressures by responding flexibly to them.

We claim:

1. An underground storage tank for liquified gas comprising:

a. an opening in an earthen surface;

b. a container made of a laminate and conforming when filled to the shape of said opening;

c. porous reinforcing screening covering the floor and wall of said opening and serving to surround and gird said container; and

d. thermal insulation distributed between said screening and the floor and wall of said opening and a thermally insulated roof covering the top of said opening.

2. The storage tank of claim **1** characterized further by a plurality of expanding retention bands located within said screen at vertically spaced intervals between said screening and the side of said container and pressing said screening against said thermal insulation to hold said thermal insulation in place.

3. The storage tank of claim **2** characterized further by a moisture-impervious liner surrounding the thermal insulation which is distributed between said screening and the floor and wall of said opening and a layer of padding distributed between the wall of said opening and said liner to protect said liner from puncture.

4. In an underground storage tank for liquified gas of the type having an opening in the earth's surface and a container in said opening, a thermally insulated roof comprising:

a. a concrete ring surrounding the lip of said opening;

b. a net of steel cables stretched across said opening and supported by said concrete ring;

c. screening of cryogenically stable material extending on top of said net;

d. a moisture-impervious laminate extending on top of said screening; and

e. thermal insulation packed in bags and distributed in several layers on top of said laminate.

5. 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;

b. thermal insulation packed in bags and distributed in a continuous layer between the inner and outer walls of said liner;

c. a porous reinforcing screen surrounding the inner wall of said liner;

d. a liquid and gas impervious diaphragm stretched 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.

6. 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;

b. thermal insulation packed in bags and distributed in a continuous layer between the inner and outer walls of said liner;

c. bracing means for maintaining said bags of insulation upright against the wall of said opening and for reinforcing the inner wall of said liner, said bracing means including,

1. cryogenically stable bucket-shaped screening surrounding the inner wall of said liner, and

2. a series of vertically spaced apart, expandable, cryogenically stable retainer bands between the upright portion of said screening and the upright portion of said inner wall for holding said screening against said insulation;

d. a liquid and gas impervious diaphragm stretched 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.

7. For use in storing liquified gas in a bucket-shaped opening in the earth's surface a thermally insulated container comprising in combination:

a. a bucket-shaped liquid and gas impervious liner within said opening;

b. compressible pillows of thermal insulation distributed in a continuous layer inside said liner along its floor and wall;

c. a bucket-shaped expandable cryogenically stable reinforcing screening inside said layer of bags;

d. a series of vertically spaced apart, expandable, cryogenically stable retaining bands compressed inside said screening;

e. a bucket-shaped liquid and gas impervious liner within said series of retaining bands, made expandable by distributed folds;

f. a liquid and gas impervious diaphragm stretched across the mouth of said opening and sealed to the rim of said inner liner; and

g. thermal insulation distributed in a continuous layer above said diaphragm, said container being characterized in that its inner liner, its retaining bands, and its screening all expand and said compressible pillows are compressed when said tank is initially filled.

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