

[54] **STRUCTURE FOR STORAGE OF LIQUIFIED GAS**

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[51] Int. Cl. **F17c 1/08**

[58] Field of Search 62/45, 74, 259; 52/405; 220/9 LG

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[57]

ABSTRACT

A prestressed concrete structure for the storage of liquified gas comprises an inner and outer concrete facing maintained in spaced relationship. Insulating material is positioned between the facings and the inner facing is saturated with moisture. When the structure is filled with liquified gas, the tension due to thermal stresses is partially relieved and both facings act together to withstand the forces on the structure.

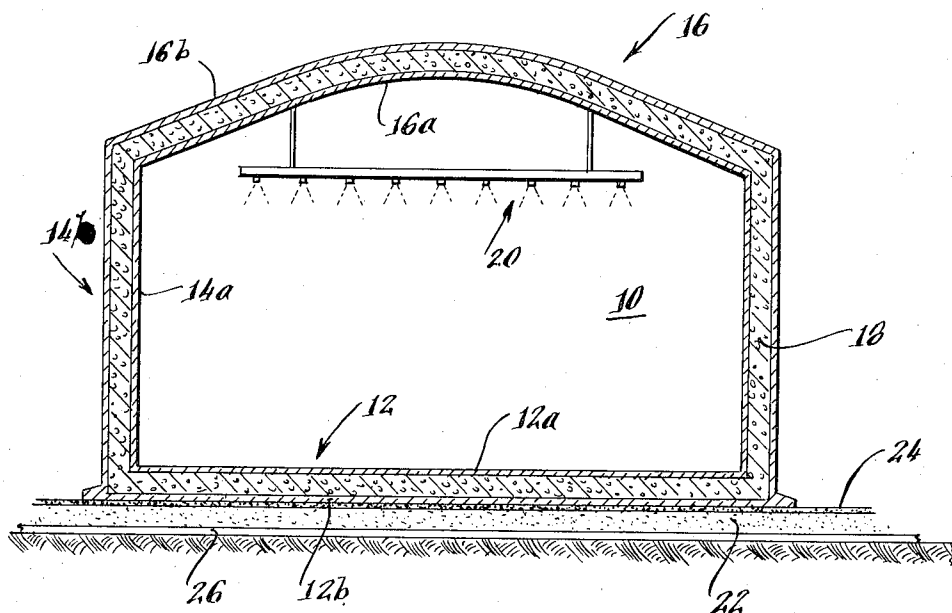
11 Claims, 10 Drawing Figures

[56]

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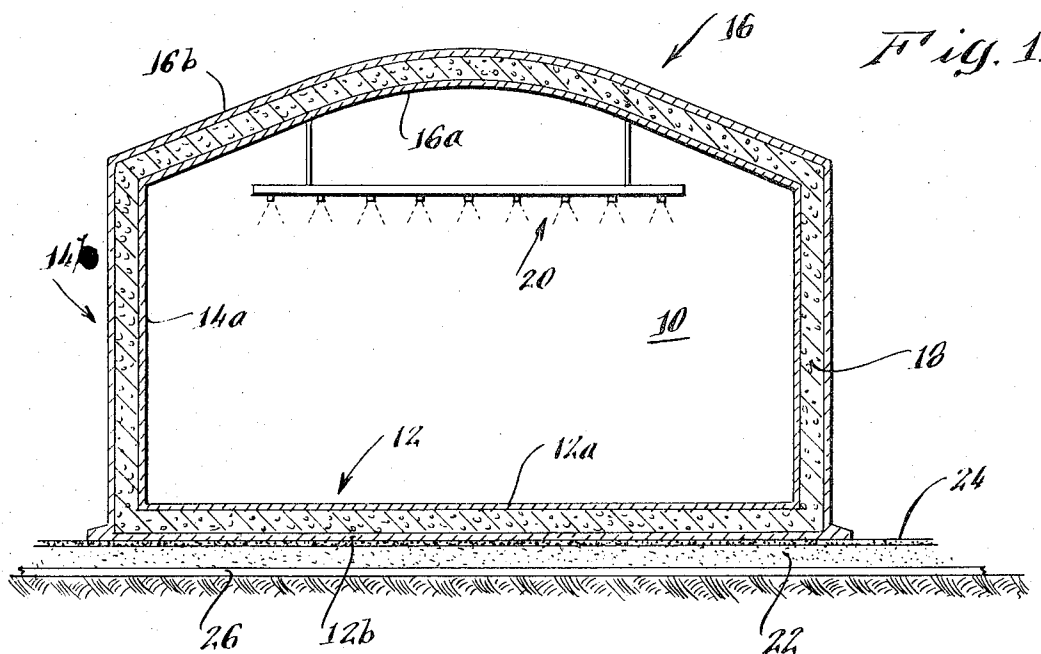


Fig. 2.

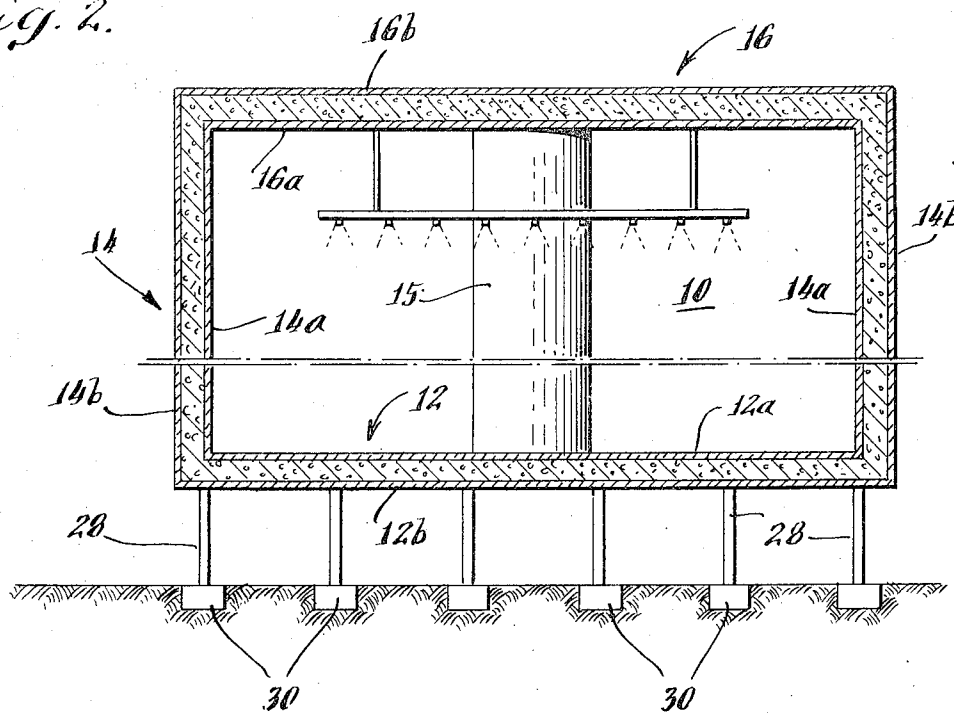


Fig. 3.

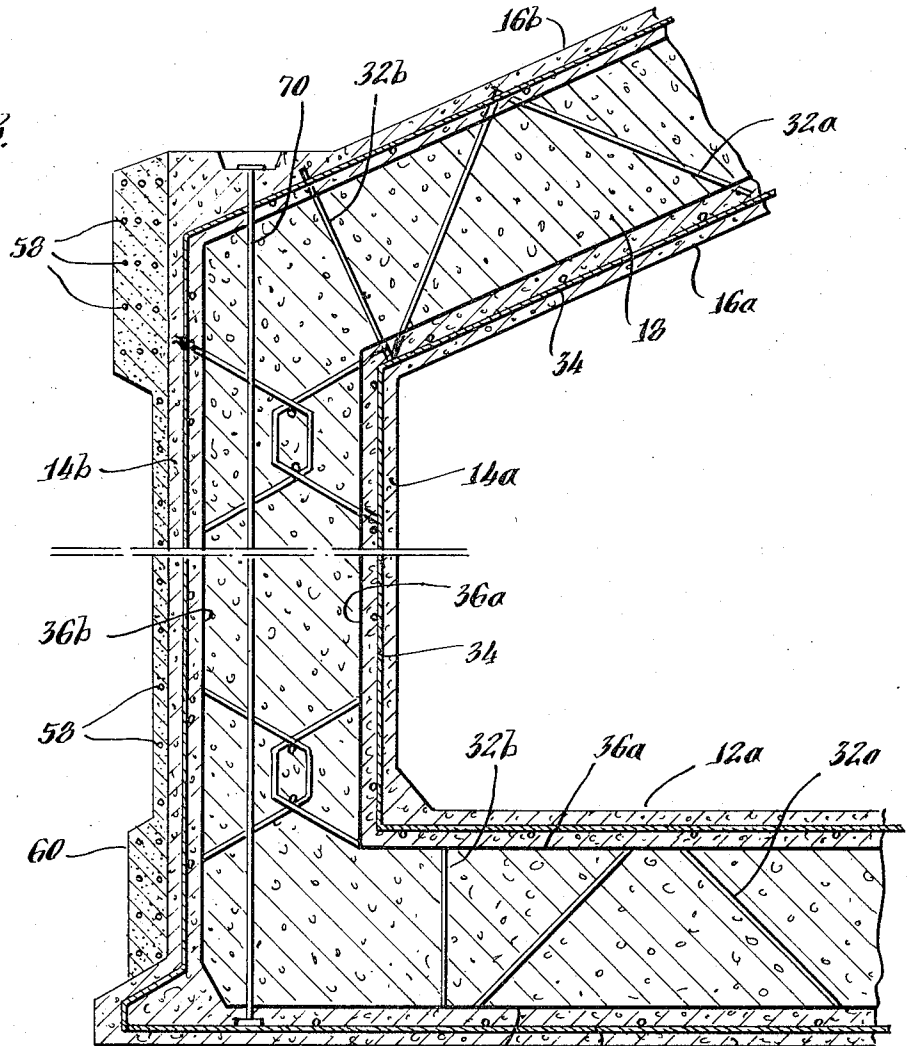
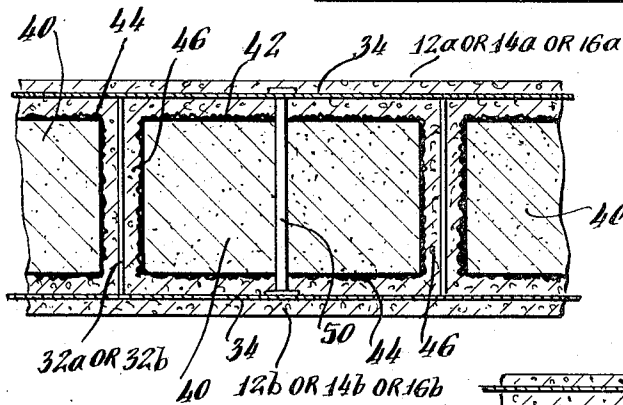
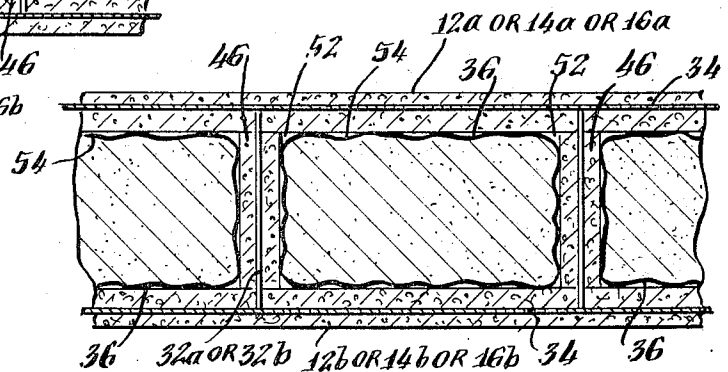
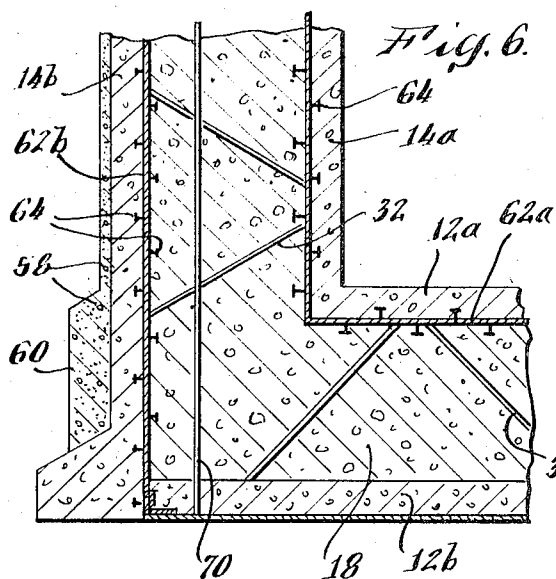
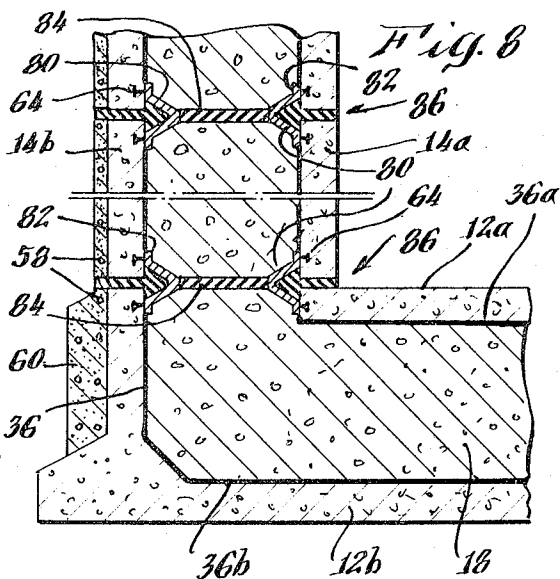
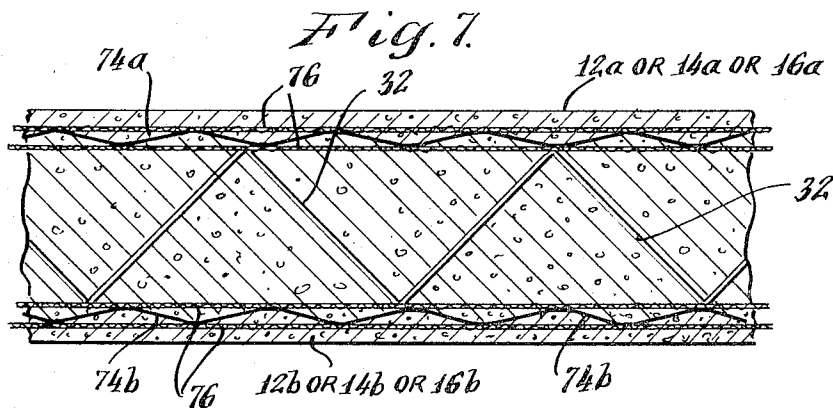
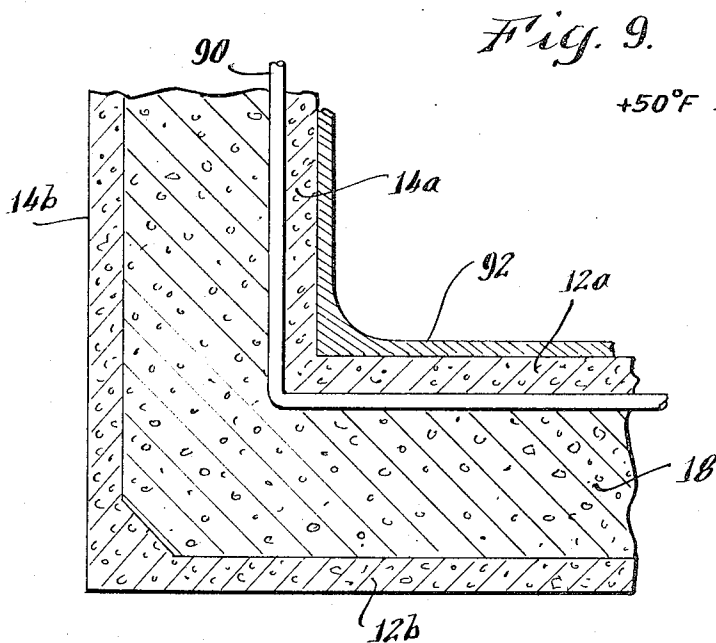
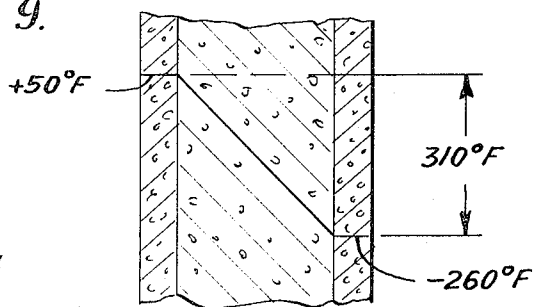


Fig. 4.

Fig. 5.





STRUCTURE FOR STORAGE OF LIQUIFIED GAS

BACKGROUND OF THE INVENTION

The invention relates to structures for storing liquified gases which are maintained at very low temperatures.

Many gases, such as methane, nitrogen and natural gas are stored in liquid form at very low temperatures thus permitting large quantities of gas to be stored in a limited volume of space. Due to the hazards inherent in the storage of any liquified gas, it is imperative that the storage structure be liquid and vapor tight and be resistant to fire, explosion, shock or other accidental, unpredictable loading conditions which may occur during the lifetime of the tank. These conditions are particularly important when dealing with the storage of natural gas since in many areas of the country there is an unusual demand for natural gas during the cold winter months when heating requirements are high and these liquid storage structures are usually constructed near populated areas.

One type of storage structure for liquified gases which is presently being used consists of a relatively thick wall having rigid insulation attached to the inner face of the wall and further having a flexible inner liner attached to the inner surface of the rigid insulation. This type of construction called single walled is particularly vulnerable to a condition known as icing. When the tank is in use, the inside of the tank becomes very cold due to the extremely low temperature of the liquified gas. Cracks occur in the insulation due to thermal shrinkage of the insulation. These cracks may be so wide and at such large spacing as to cause breaks in the inner lining of the tank thereby causing the tank to lose its vapor barrier and become structurally weaker.

A second type of construction which can be used for low temperature storage is called a double wall construction. In this type of construction, two relatively thin facings are supported in spaced apart relationship with a loose insulation between them. Each wall acts independently to carry the load upon it since the forces and stresses on one wall are not transmitted through the loose insulation to the other wall. Hence, the extremely large stresses placed on the inner wall or facing when the cold liquid is introduced into the tank must be borne by that wall alone, making this type structure relatively weak.

Another type of construction which has been used in applications other than low temperature storage structures is called the sandwich type construction. In this type of construction, two load bearing members are maintained in spaced apart relationship by rigid supporting members. With this type of construction forces on one load bearing member are transmitted through the struts to the other member and both members act to withstand forces upon the structure. While a sandwich type construction is desirable for its high strength and economy, it has not been heretofore used for storage of cold liquids because the temperature differential between the cold inner portion of the structure and warm outer portion of the structure created thermal stresses beyond the allowable stress range of most materials.

However, I have invented a new structure for the storage of low temperature liquified gases which utilizes the sandwich type construction and which is easy

to construct and posses extremely high strength and safety against internal and external explosions, fires or penetration by high velocity projectiles.

SUMMARY OF THE INVENTION

The invention relates to the storage structure for low temperature applications and particularly to storage structures for liquified gases.

In accordance with the invention, a structure for the storage of low temperature liquified gases comprises an inner and outer concrete facing maintained in a spaced apart relationship. The inner facing forms a continuous enclosure for the liquified gases. Insulating material is positioned in the space between the inner and outer facings. The inner and outer facings are cooperatively arranged so that the loading on the structure is shared by both facings.

In a preferred embodiment of the invention the insulating material is a rigid material which served to distribute the forces between the inner and outer facings. Insulation such as insulating concrete, balsa wood, foamglass or combinations thereof are particularly well suited for this purpose.

As an important feature of my invention, the inner concrete facing is saturated with moisture. I have found that by utilizing an inner concrete facing which is saturated with moisture large thermal stresses between the facings can be substantially reduced. Light weight concrete is especially suitable due to its low elastic modulus and thermal contraction coupled with its large shrinkage and excellent water absorption capacity.

I have found that since the strength and elastic properties of saturated concrete increase markedly under cold conditions, the thermal stresses which would normally be present without saturation are partially released when the tank is cooled down by the addition of the cold liquid gas. The shrinkage differential between the inner and outer facings then substantially eliminates the remaining thermal stresses in the structure. In addition, ice is formed in the pores of the concrete which forms a vapor barrier to prevent vapors from escaping from the tank.

As a further aspect of the invention, an additional liner is formed in the structure to serve as a vapor barrier for the insulating material. This barrier can be formed by encapsulating the insulating material in epoxy or other moisture protective coating.

As still another aspect of the invention, the wall may be fabricated with a cellular structure with the cells filled with loose insulation material.

As still another aspect of the invention, the storage structure utilizes prestressed concrete and steel composite construction. In this embodiment, a steel plate is positioned between each facing and the rigid insulation. The liners serves to increase the load carrying capability of the structure and act as additional vapor barriers.

As still a further aspect of the invention, a cold liquid is circulated through pipes positioned proximate the inner facings of the structure after the structure has been filled with water. The ice layer formed on the inner facings is an impervious liquid and vapor barrier.

For a better understanding of the present invention together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, the scope of

the invention being pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical cross sectional view of a tank in accordance with the present invention.

FIG. 2 is a partial vertical cross sectional view of the tank with alternate roof and foundation design.

FIG. 3 is a partially fragmentary view of a wall, floor and roof section of the structure of FIG. 1.

FIG. 4 is an enlarged detail of an alternate sandwich shell construction in accordance with the present invention.

FIG. 5 is an alternate detail of FIG. 4, showing the use of loose fill insulation in cellular construction.

FIG. 6 is a sectional detail showing a steel concrete composite construction alternate.

FIG. 7 is a modified form of FIG. 5.

FIG. 8 is an enlarged fragmentary sectional detail of an alternate hinged connection between the floor and the wall.

FIG. 9 is a graphic representation of the temperature distribution on the sandwich concrete wall of a structure which is in accordance with the present invention.

FIG. 10 is a sectional detail showing the use of cooling pipes near the inner facing of the wall.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings and to FIGS. 1, 2 and 3 in particular, a prestressed concrete storage structure 10 for storing liquified gases is shown. The tank 10 has three major components: a floor 12, a substantially cylindrical wall 14, and a roof or dome structure 16. Each of the major components has concrete inner facings 12a, 14a, and 16a and concrete outer facings 12b, 14b and 16b respectively. The concrete facings are preferably formed of lightweight concrete weighing about 100 lbs/cu. ft., the facings are preferably about 6 inches thick and are maintained in spaced apart relationship with the space between the faces which is preferably about 4 feet filled with insulating material 18. Of course, the dimensions of the facings and space between the facings can be varied according to particular design requirements and these dimensions are only representative. The insulation material is preferably a rigid, insulating concrete weighing approximately 20-50 lbs/cu. ft. Zonolite, Perlite, Permalite and Mearlcrete are examples. Other type insulation such as balsa wood, or foamglass may also be used. The rigid insulation transmits shear between the facings causing the facings to share any loading stresses placed upon the structure. The facings thus act together to insure a substantially stronger structure than was heretofore known.

Referring now to FIG. 3, there is shown in more detail an embodiment of the present invention. Thus, as shown, concrete facings 12a, 14a and 16a are connected by dowel reinforcement 32 to the outer facings 12b, 14b and 16b in order to prevent separation of the facings and to further increase the shear resistance of the insulation 18 and increase the load carrying capability of this structure. The dowels 32 may advantageously be made of strands or wires which have high strength and are not embrittled at cold temperatures. The facings 12a, 12b, 14a, 14b and 16a, 16b may also

be advantageously reinforced with regular mild steel reinforcement 34, in order to control shrinkage and cracking and to increase the strength of the structure. The surfaces between the insulation and concrete facings may advantageously be sealed against moisture by, for example, epoxy paint as shown at 36a and 36b.

To construct the storage structure facings 12b is poured on the ground with dowels 32 anchored in place. Then sealant 36b is applied and insulation concrete 18 poured. After drying the upper sealant 36a is applied and finally concrete facing 12a is poured. The construction of the roof is similar.

Unless it is precast in a horizontal position, the construction of the wall requires a somewhat different approach. Wall facings 14a and 14b may be slip formed first and insulation 18 poured between them. Alternatively, insulation 18 may be slip formed first and concrete facings 14a and 14b applied by a pneumatic (gunite) process. In either event, dowels 32a, 32b must be cast against the concrete forms and bent into final position after the insulation is placed.

The walls, floor and dome are prestressed in two directions. Vertical tendons 70 in the wall prestress the wall facing in the vertical direction while a series of wires or tendons 58 are wound around the entire periphery of the tank to prestress the tank in the other direction. These tendons are further covered by a protective concrete coating 60. Curved tendons 72 placed over the dome in two perpendicular directions prestress the dome. The floor is prestressed by placing additional tendons on the wall or floor. As shown, all facings are monolithically connected with each other without the need for joints or other connectors.

Returning to FIG. 1, as an important feature of this invention a spray system of fog nozzles 20 preferably arranged in a circular ring is attached to the roof of the structure. Prior to using the tank, water is emitted from the nozzles to fully saturate the concrete inner facings of the floor, wall and roof.

Since the elastic, shrinkage and creep properties of concrete at different temperatures are markedly dependent on the level of water saturation, by maintaining the inner facing in saturated conditions while the outer facing is dry, differential elastic, shrinkage and creep strains can be set up between the two facings. When the tank is filled with liquified gas at low temperature, the strength and elastic modulus of the fully saturated concrete inner facings increases, partially relieving the tension due to thermal stresses. Furthermore, while at low temperature there is no shrinkage in the inner facing, shrinkage will occur in the outer facing further decreasing the compression of the outer facing thus equalizing the stresses between the two facings. Also, due to the freezing of the moisture trapped in the pores of the concrete when the low temperature liquified gas is introduced into the tank, an impermeable vapor barrier is created. Furthermore, the necessity of sliding joints between the different parts of the structure can be eliminated by uniformly cooling down the inside of the structure prior to the introduction of the liquified gas. This can readily be accomplished by spraying a predetermined amount of liquified gas into the structure through nozzles 20.

Tank 10 may be constructed directly on the ground as shown in FIG. 1 in which case a layer of fine sand 22 and friction relieving material 24 is placed under the floor to allow the floor to slide relative to the ground.

Heating cables 26 may be included to prevent freezing of the soil underneath the structure.

Tank 10 may also advantageously be elevated above the ground by pendulum support columns 8, as shown in FIG. 2, which rest on reinforced concrete footings 30 directly on the ground. These pendulum supports are designed to allow radial motion only while resisting tangential motion to insure the lateral stability of the tank. As also shown in FIG. 2, the structure can be constructed with a flat roof which is supported by a circular central column 15.

Another embodiment of the invention is shown in FIG. 4 wherein preformed rigid insulation such as balsa wood or foamglass is used. The insulation can be assembled into large blocks 40. The blocks are encapsulated by a resin coating 42 to provide a vapor seal at the time of manufacture. The resin coating 42 may be made rough by the addition of stone or gravel 44 embedded in the coating. These blocks are positioned between the inner and outer facings of the floor, walls or roof and insure the proper shear transmission between the facings. The block 40 can also serve as forms for the casting of webs 46 into which reinforcing dowels 32a or 32b may be embedded.

To construct a storage tank using preformed insulating, outer floor facing 12b is poured first. While the concrete is still fresh, that is, not fully cured, blocks 40 are placed on the facing. In order to allow air to escape and to hold the insulation block down bolt 50 is placed through a cylindrical cavity 48 in the center of the block for anchorage. Following placement of blocks 40, the webs 46 made of insulating concrete are cast. A coating of epoxy is applied on the top of the insulating concrete and bolt head as a sealant. Finally, the inner facing 12a is poured in place. The roof construction is similar. In constructing the wall, several approaches are possible. The insulating blocks 40 may be erected first and the vertical webs 46 with dowels 32 may be cast in place and finally the two concrete facings sprayed on using the pneumatic mortar. Alternatively, the wall facings can be slip formed and the insulating blocks 40 placed between them.

Referring to FIG. 5, the facings, for example, 14a, 14b and webs 46 are slipformed leaving cells 52 between the webs. Plastic bags 54 containing a loose lightweight insulating material such as Perlite are placed in the cells. The webs are sealed against vapor transmission by coating 36. The outside facings 14b are finally sealed by coating.

FIG. 6 shows a composite steel concrete construction. The tank is constructed as described above with the addition of steel liners 62a and 62b which are held in place with anchor stud 64. While the steel liner at the outer floor facing may be positioned between the facing and insulating material, it has been found that construction is simplified if the liner is placed outside the outer facing as shown. Space between the two steel liners is filled with insulating concrete or other appropriate insulating material. Dowels 32 may also be used.

After the wall, floor and roof are complete, the structure is prestressed by wrapping the periphery with a series of prestressing tendons or wires protected by a concrete cover 60. In this manner the concrete is precompressed to its allowable limit and the steel is precompressed beyond its yield point. However, there is no danger of buckling or further plastic strain since the steel and concrete wall act together.

Prestressing releases the residual tensile stresses created in the steel at the time of welding the liners. Thus, the structure utilizes the strength of steel over a larger stress range than normally possible. Cryogenic steels, for example, will be effective from their yield point of compression to their allowable stress level of tension and even regular carbon steels would be useful in their full compression range. This is particularly important since with earlier attempts to incorporate carbon steel liners into single walled storage structures, the liner served only as a vapor barrier since the compression created by the prestressing of the structure was not high enough to relieve residual stresses which were present in the steel. When used in this invention, the steel liner provides additional strength to the structure.

In addition, precompression causes compression of the insulation between the facings. This is of such a magnitude that the problem of icing is eliminated.

FIG. 7 shows an alternate embodiment of the metal liner insulating system. As shown therein, the flat steel plates 62a and 62b of FIG. 6 are replaced by thin gauged corrugated metal sheets 74a and 74b with wire mesh 76 secured as by welding onto both sides.

In the previous embodiments of this invention, the walls, floor and roof and dome are prestressed in two directions to relieve tensile stresses thereon and all facings are monolithically connected together. It is possible to relieve these stresses in another manner by the introduction of artificial hinges. These hinges allow the wall or roof to warp or curl. Provided that enough hinges are used, the thermal stresses will be relatively small in the vertical and radial direction.

FIG. 8 shows the actual construction of such hinged joints. As shown, the facings are discontinuous at the location of the joints 86 and folded metallic sheets 80 with two flaps 82 are used to seal the joints. The two flaps are attached to the walls by anchor studs 64. Epoxy or welds seal the flaps. The wall and dome include a layer of rigid urethane blocks 84 which are of sufficient strength and elasticity to carry the load and to allow rotation at the joint. The gap between the facings is chalked with urethane foam or similar material. The folded metallic sheets 80 allow widening or closing of the joint in the facings. In addition, they provide restraint against tangential displacement between the different parts of the structure separated by the joint. Hence, the structure is stable with respect to the effects of earthquake, blast or other shifting forces which may occur.

FIG. 9 shows a graphic representation of temperature distribution in the structure.

FIG. 10 shows still another embodiment of the invention. As shown, a piping system 90 is embedded or positioned proximate to the inner facings of the structure. The structure is filled with water or the air saturated using fog nozzles 20 as shown in FIG. 1. Cold liquid is then circulated through the piping system and an ice layer 92 forms on the inner surface of the tank. After a predetermined ice thickness, preferably about 1/2 inch, is obtained, the structure is drained of water and the cooling of the structure continued until the final temperature is reached.

What is claimed is:

1. A structure for the storage of liquified gas maintained at low temperatures comprising, a structural element forming at least part of said storage structure

comprising in combination an inner and an outer concrete facing maintained in spaced-apart relationship, a rigid insulating material positioned between said inner and outer concrete facings, means for saturating said inner facing with moisture, said inner and outer facings and insulating material cooperatively arranged so that loading on the structure is resisted by both the inner and outer concrete facings.

2. the storage structure of claim 1 wherein said structural element forms the floor, wall and roof of the storage structure and wherein said storage structure further includes means for precompressing said structure.

3. The storage structure of claim 2 wherein said storage structure further includes a plurality of nozzles positioned on the inside of said structure for supplying moisture to the interior of said structure for saturating the inner facing of said structure with moisture.

4. The storage structure of claim 2 wherein said storage structure further includes a plurality of nozzles positioned on the inside of said structure for producing an environment of 100 percent relative humidity in the interior of said storage structure.

5. The storage structure of claim 2 wherein said insulating material includes rigid connectors coupled between said inner and outer facings forming cavities therebetween, said cavities being filled with loose insulating material completely encapsulated to form a vapor barrier surrounding the loose insulating material.

6. The storage structure of claim 2 further including means formed between the inner facing and said rigid insulation and said outer facing and said rigid insulation for providing a gas and vapor-tight barrier to prevent gas or vapor from escaping from said storage structure.

7. The storage structure of claim 6 where at least one of said barriers is a metal liner positioned between one of the facings and the insulating material.

8. The storage structure of claim 6 wherein said vapor barrier is formed of a corrugated metal plate.

9. The storage structure of claim 6 wherein vapor barrier is a continuous resinous coating.

10. The storage structure of claim 2 wherein said walls further include hinged joints positioned at various preselected intervals along the wall and extending between the inner surface of the inner facing and the outer surface of said outer facing for relieving tensile stresses on the concrete facings in the vertical and radial directions.

11. A storage structure of claim 10 wherein said hinge joints extend circumferentially around the entire storage structure and comprise a central bearing pad extending between the inner and outer facings through the insulating material and connector means connecting said facings to said joints.

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