

[54] **CRYOGENIC TANK**

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[51] Int. Cl.² **B65D 25/18**

[58] Field of Search **220/9 LG, 9 L, 90, 9 F, 220/15, 10; 114/74 A; 62/45**

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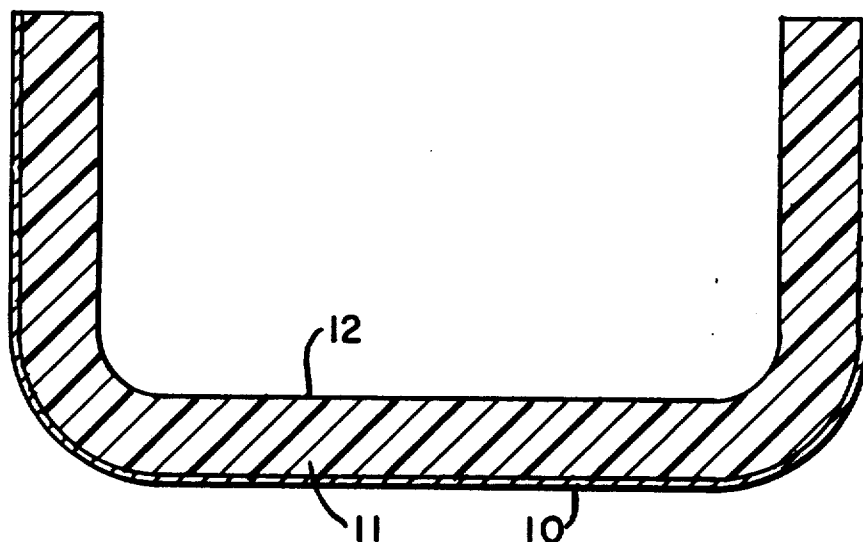
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[57]

ABSTRACT

This invention relates to an internally insulated tank for the transportation and storage of cryogenic liquids, such as liquified natural gas. The inner surfaces of the tank are lined with rigid, closed cell polyurethane foam to which is bonded a thin impervious sheet material, such as aluminum foil.

11 Claims, 5 Drawing Figures



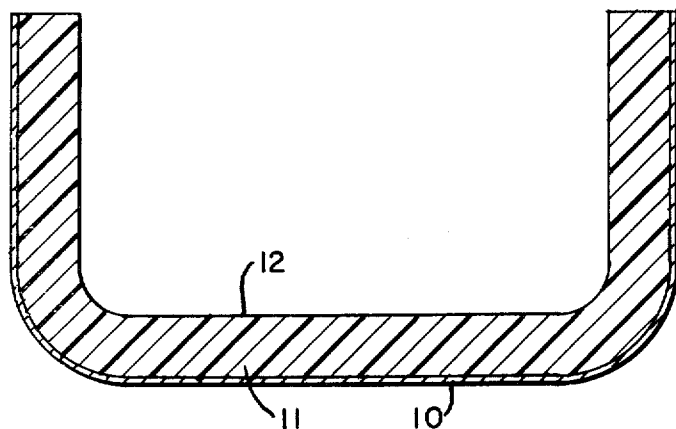


FIG. 1

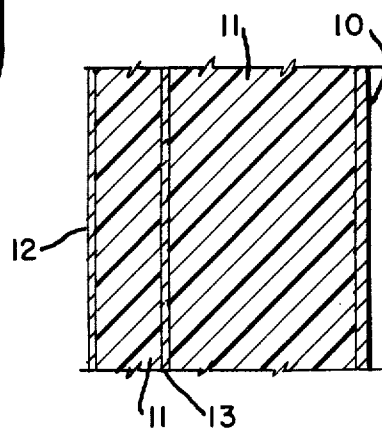


FIG. 2

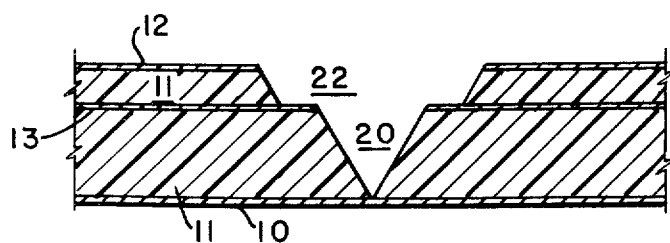


FIG. 3

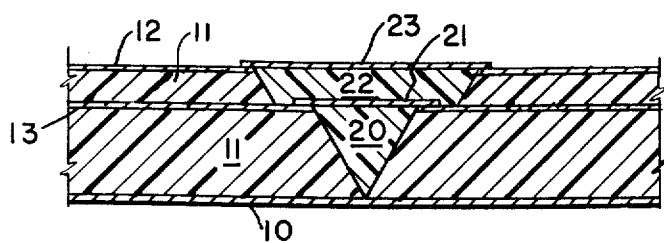


FIG. 4

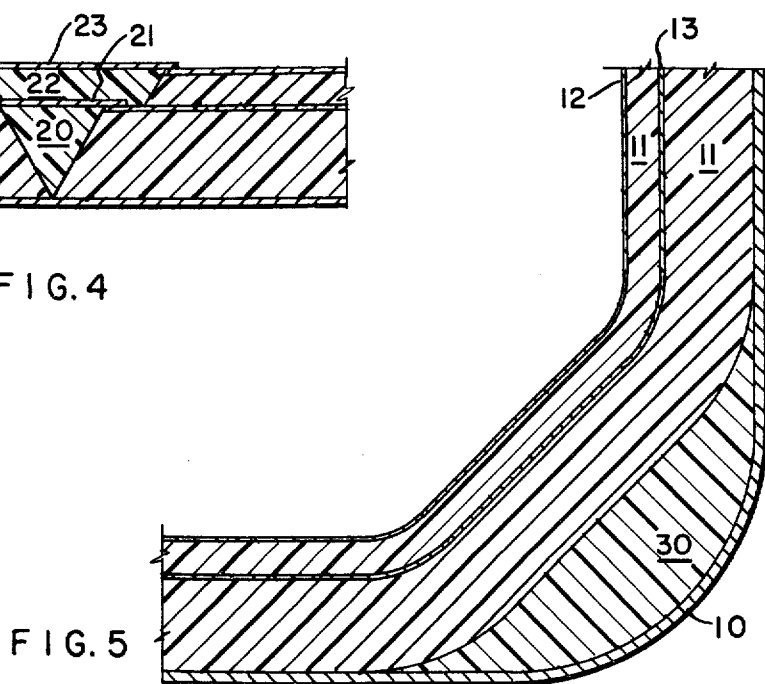


FIG. 5

CRYOGENIC TANK

BACKGROUND OF THE INVENTION

This invention relates to an improved insulated container for the transportation and storage of liquid at extremely low temperatures and in particular liquified natural gas (LNG).

Over the past few years, the need for natural gas in various parts of the world has increased considerably. Those areas of the world which have the highest need for natural gas, namely, Japan and the United States, are or are becoming deficient in this natural resource. The only present economical method for the transoceanic shipment of natural gas is to transport it in the liquid state, generally at a temperature of about -260°F . at approximately atmospheric pressure. However, LNG container operating temperatures, which range from ambient temperature to about -260°F ., impose rather severe requirements on the selection of the construction materials and the design of both the tank and the transporting vessel itself. For transoceanic transport, most container designs to date generally have been of two types, namely, a free-standing tank and a membrane tank. Generally, the freestanding tank rests on insulation material on the bottom of the ship. Insulating materials, such as perlite, PVC foam, polyurethane foam, fiberglass or combinations thereof, are provided between the upstanding inner tank walls and the bulkhead or inner hull. Because the free-standing tank is in direct contact with the cryogenic liquid, it must be formed from materials which are not subject to brittle failure at the low temperatures, such as aluminum, stainless steel or 9% nickel steel. The membrane tank generally comprises a thin metal sheet of Invar, 9% nickel steel or stainless steel about 0.015 to about 0.02 inch thick, which is supported both on the bottom and along the sidewalls by insulation which is attached to or supported by the ship's bulkhead or inner hull. Both tank designs require complex structure and insulation design to compensate for the large differential expansion and contraction of the various components of the tank and ship during service. For an excellent discussion of the various types of tank designs, see the paper presented by Thomas et al. to the Society of Naval Architects and Marine Engineers, Nov. 11-12, 1971, entitled, "LNG Carriers: The Current State of the Art".

The U.S. Coast Guard and other regulatory agencies presently require both a primary and a secondary barrier layer to assure that the LNG does not contact the ship's hull or bulkhead because the LNG will crack or embrittle the normal steel plate. The primary barrier layer is designed to contain the LNG or other cryogenic liquid and the secondary barrier layer is designed to act as a safety factor in case the primary barrier layer fails.

Heretofore, no simple and economical tank design has been developed for the transportation and/or storage of large quantities, e.g., 2,000 gallons or more, of LNG and other cryogenic liquids.

Against this background, the present invention was developed.

SUMMARY OF THE INVENTION

The present invention is directed to an internally insulated tank or container for the transportation or storage of large quantities of liquids at extremely low temperatures, such as liquified natural gas (LNG). A

rigid, closed cell polyurethane foam is bonded to the internal surface of the tank shell. A thin layer is bonded to the innermost surface of the foam. The material of the impervious layer, such as aluminum, has a lower coefficient of expansion than the foam, a higher strength than the foam and maintains its ductility at cryogenic temperatures. Preferably, a second thin layer of impervious material is disposed within the polyurethane foam as an additional barrier layer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of an insulated tank of the present invention.

FIG. 2 is a cross-sectional view of a preferred embodiment.

FIGS. 3 and 4 are cross-sectional views of a preferred joint construction.

FIG. 5 is a cross-sectional view of a preferred corner construction.

In the drawings, all corresponding parts are numbered the same.

DESCRIPTION OF THE INVENTION

The present invention provides for a relatively simple and inexpensive container for the transportation and/or storage of a liquid at or about atmospheric pressure and at temperatures from about -50° to about -400°F . More particularly, the insulated container of the present invention comprises an outer support shell and an internal, thermal insulating lining comprising a layer of rigid, closed cell polyurethane foam having a density of about 2-10 pounds ft^3 . Onto the inner surface of the polyurethane foam is bonded a thin impervious layer of material which has a lower coefficient of thermal expansion and a considerably greater tensile strength than the polyurethane foam, and, moreover, which has high ductility at the operating cryogenic temperatures. By use of the term "impervious" is meant that the material prevents penetration of the cryogenic liquid or any component in the cryogenic liquid.

Reference is made to FIG. 1 which represents a cross-sectional view of a tank of the present invention. As indicated, the polyurethane foam 11 is bonded or affixed in a suitable manner to the inner surfaces of the support shell 10. A thin impervious layer of sheet 12 is bonded to the inner surfaces of the layer 11 of polyurethane foam. FIG. 2 represents a preferred embodiment of the present invention wherein a second impervious layer 13 is incorporated in the polyurethane foam to act as a barrier layer which provides an additional safety factor should the impervious layer 12 and underlying layer of foam fail in service. Preferably, layer 13 is disposed within foam layer 11 at a distance from layer 12 of about one-eighth to one-third the thickness of foam layer 11. Thus should an insulation failure occur such that cryogenic liquid penetrates to layer 13 sufficient insulation remains to prevent significant vaporization of the cryogenic liquid.

To form the insulated container or tank of the present invention, the support shell is usually cleaned and prepared with a suitable primer, the polyurethane is foamed in place, and then the impervious layer, preferably aluminum foil or the like, is bonded to the surface of the polyurethane foam. A suitable bond between the polyurethane and impervious layer usually can be obtained by applying the impervious layer and the polyurethane foam in the same operation. The bond between the impervious layer and foam should be at least

as strong as the foam itself.

Although it is most convenient to foam the polyurethane in place, it is within the scope of the present invention to adhesively bond or affix in a suitable manner a previously prepared block of polyurethane foam onto the inner surfaces of the support shell. The impervious layer can be bonded to the polyurethane foam block before or after the polyurethane foam block has been installed on the inner surfaces of the tank. This type of construction, however, usually necessitates some preparation of the joining surfaces of the insulating blocks.

FIGS. 3 and 4 describe an improved joint construction, wherein FIG. 3 represents the unprepared joint, and FIG. 4 represents the completed joint. In preparing the joint, the lower groove 20 is filled with polyurethane foam either by spraying or pouring the foaming polyurethane into the groove. A covering strip of impervious material 21 is positioned over the groove 20 as the polyurethane foam is curing, and thus is bonded thereto. If desired, the impervious layer can be bonded by suitable adhesives to previously cured polyurethane foam in the groove. The upper groove 22 is then filled with foaming polyurethane in a similar manner to the foam in groove 20 and again preferably a strip of impervious material 23 may be positioned on top of the polyurethane foam. Usually, it is desirable to have a slight excess of polyurethane foam to allow a bead of polyurethane foam to form on the outer edges of the impervious layer, thus assuring a good bond of the impervious layer to the underlying surfaces.

Reinforcing netting or webbing, such as nylon, glass fiber or burlap, can be incorporated into the polyurethane foam, such as during the formation thereof, to increase the strength of the polyurethane foam and to act as a crack arrester. If the support tank is of rectangular or trapezoidal shape, corner blocks of polyurethane foam or other insulating materials can be incorporated into the corners to reduce the sharpness of the corners and thus minimize the stress concentration and to allow the corner to absorb the high tensional and torsional loads without failure during tank usage. If desired, the corner blocks can be of higher density insulating material for added strength. A suitable corner construction is shown in FIG. 5 wherein the corner blocks are indicated by numeral 30.

In accordance with the present invention, the thin impervious layer has a substantially lower coefficient of expansion than the outer surfaces of the polyurethane foam to which it is bonded. Usually a coefficient of expansion of at least 5×10^{-6} , preferably more than 10×10^{-6} , (in/in/°F) less than the polyurethane foam is adequate. This layer restricts the contraction of underlying surface of the polyurethane foam at the cryogenic temperatures, thus minimizing the cracking which is characteristic of most polyurethane foams at very low temperatures. Moreover, the thin impervious layer should have a high ductility, at the cryogenic temperatures because if small cracks do occur in the polyurethane foam, the impervious layer can plastically deform and thereby prevent any leakage of the low temperature liquid into the crack in the polyurethane foam which may accelerate crack propagation. The thin impervious layer also advantageously prevents any erosion of the foam surface by movement and slashing effect of the cold liquid during transportation thereof and also prevents any damage to the foam surface by workers during the construction or the repair of the

container. The material of the impervious layer should have a tensile strength of at least about 5,000 psi and an elongation of at least 10% (in two inches) at the cryogenic temperatures. As used herein, the term "thin" refers to a thickness less than 0.015 inch.

The preferred impervious layer is thin aluminum sheet or foil because of the high strength and elongation characteristics of aluminum at cryogenic temperatures. The thickness ranges from about 0.001 to about 0.01 inch. Suitable aluminum alloys include 1100, 1145, 5052 and 3003 (Aluminum Association alloy designations). As used herein, the term "aluminum" refers to pure aluminum or any alloy containing more than 50% by weight aluminum. A recurring pattern may be embossed on the aluminum foil to minimize glare during the construction and repair of the tank and also to provide stress relief so that the aluminum foil will easily deform and reduce stress at the operating cryogenic temperatures. A further advantage of aluminum is the fact that it readily bonds to the polyurethane foam while the foam is curing. Other materials which have the aforesaid properties could, of course, be employed.

As is well known in the art, the polyurethane foam can be prepared by reacting an organic polyisocyanate with an organic compound containing a plurality of active hydrogen atoms as determined by the Zerewitinoff method, JACS, Vol. 49, pages 3181 and 1929. Suitable compounds having active hydrogen atoms include polyhydroxy compounds, such as polyols and the like. Suitable additives may be incorporated into the polyurethane foam, such as light and heat stabilizers, catalysts, fillers, pigments, pore size regulators, foaming agents, solvents, viscosity controllers, surface active agents, such as silicone oils, fire retardants and the like. Preferably, the polyisocyanate contains 35-85% methylene diphenyl diisocyanate. For the present invention, the density of the foam should range from about 2-10 pounds/ft³, preferably about 2.5-5 pounds/ft³. Tensile strength of the cured foam should exceed 50 psi preferably greater than 100 psi and the elongation should exceed 4% at -260°F. The compressive strength at room temperature (72°F.) should exceed 20 psi. The coefficient of thermal expansion generally ranges from about 20 to about 50×10^{-6} in/in/°F. the K factor (BTU-/in/ft²/hr/°F. based on ASTM test C177) is generally below 0.2, usually less than 0.1 at -260°F.

Usually, when the polyurethane foam is sprayed in place, no more than about 1.5 inches of foam is applied per pass, and, therefore, for most applications, several passes are usually required. If desired, reinforcing netting or additional layers of aluminum foil can be incorporated between these various layers of polyurethane foam. However, both the netting and the foil should be bonded to the adjacent layers of foam. For most applications, the overall foam thickness generally ranges from 2-24 inches, although the thickness will vary depending upon the insulation requirements of each installation. If desired, the density, and thus the strength of the separate layers of polyurethane foam, can be varied within the density ranges provided above.

Generally, rigid closed cell polyurethane foam is impervious to most cryogenic liquids, particularly LNG. Thus, the foam and the impervious layers of the present invention provide a plurality of barrier layers to prevent the penetration of the cryogenic liquid to the support shell should one or more of the barrier layers fail.

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By use of the internal insulation of the present invention, the temperature of the structural shell usually does not vary far from the ambient temperature and thus may be formed from any convenient material, e.g., such as aluminum, steel or reinforced fiberglass and the like. However, as an added safety feature, in case of the complete failure of the insulation system, it may be desirable to form the tank from materials which can withstand cryogenic temperatures, such as aluminum, stainless steel, Invar and 9% Ni steel. The thickness of the tank walls generally ranges from about $\frac{1}{4}$ to 3 inches. Because the temperature of the support shell does not vary far from the ambient temperature, the complexity of the support structure for the shell is significantly reduced.

The present invention has generally been described in terms of a tank having a rectilinear cross section, but it is obvious that the tank can be spherical, cylindrical or any convenient shape. Moreover, other modifications and improvements can be made to the present invention without departing from the spirit thereof and the scope of the appended claims.

What is claimed is:

1. An internally insulated tank capable of storing or transporting a large volume of liquid at temperatures down to -260°F comprising an outer support shell, a layer of rigid closed cell polyurethane foam having a density of about 2.5 to 10 pounds/ft³ attached to the inner surfaces of said support shell and a thin impervious metallic layer less than 0.015 inch thick completely bonded to the inner surfaces of said foam layer with the bond therebetween being at least as strong as the foam to restrict the thermal contraction of said foam surface at cryogenic temperatures and thereby minimize crack formation therein, said metallic layer having a substantially lower coefficient of expansion and a substantially

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higher tensile strength than said foam and further characterized by high ductility at low temperatures.

2. The insulated tank of claim 1 wherein said impervious material has a coefficient of expansion of at least 5×10^{-6} in/in/ $^{\circ}\text{F}$. less than the foam.

3. The insulated tank of claim 1 wherein said impervious layer has a coefficient of expansion of at least 10×10^{-6} in/in/ $^{\circ}\text{F}$. less than the foam.

4. The insulated tank of claim 1 wherein said support shell is formed from a material selected from the group consisting of aluminum alloys, stainless steel, Invar, 9% Ni steel.

5. The insulated tank of claim 1 wherein said polyurethane foam is characterized by a density of about 2.5-5 lbs/ft³, a tensile strength exceeding 50 psi, an elongation exceeding 4% at a temperature of -260°F . and a compressive strength at room temperature exceeding 20 psi.

6. The insulated tank of claim 1 wherein an additional thin impervious layer is disposed within the layer of foam.

7. The insulated tank of claim 6 wherein said additional thin impervious layer is disposed within the layer of foam at a distance of about one-third to about one-eighth of the thickness of said foamed layer from the impervious layer bonded to the surfaces of said foam.

8. The insulated tank of claim 1 wherein said impervious layer is formed from an aluminum alloy.

9. The insulated tank of claim 8 wherein said aluminum alloy is selected from the group consisting of 1100, 1145, 5052 and 3003 aluminum alloys.

10. The insulated tank of claim 8 wherein said impervious layer has a thickness from about 0.001 to about 0.01 inch.

11. The insulated tank of claim 10 wherein said impervious layer has a recurring pattern embossed on the surface thereof.

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