United States Patent

[11] 3,570,701

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[54] **TANK FOR USE IN STORING LOW TEMPERATURE LIQUEFIED GAS**
3 Claims, 9 Drawing Figs.

[52] **U.S. Cl.** **220/10**
[51] **Int. Cl.** **B65d 7/22**
[50] **Field of Search** ..... 220/9 (A), 9 (A'), 10

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Assistant Examiner—James R. Garrett
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ABSTRACT: A tank for use in storing low temperature liquefied gas having a rigid outer vessel lined with a heat insulating layer and an inner vessel of a thin film construction with gently undulated camber. The peripheral dimensions of the material of the inner vessel are made relatively larger than those of the inner peripheral dimensions of the insulating layer of the outer vessel. The camber serves to relieve the hoop stress acting upon the inner vessel when it is subjected to the load resulting from the low temperature liquefied gas.

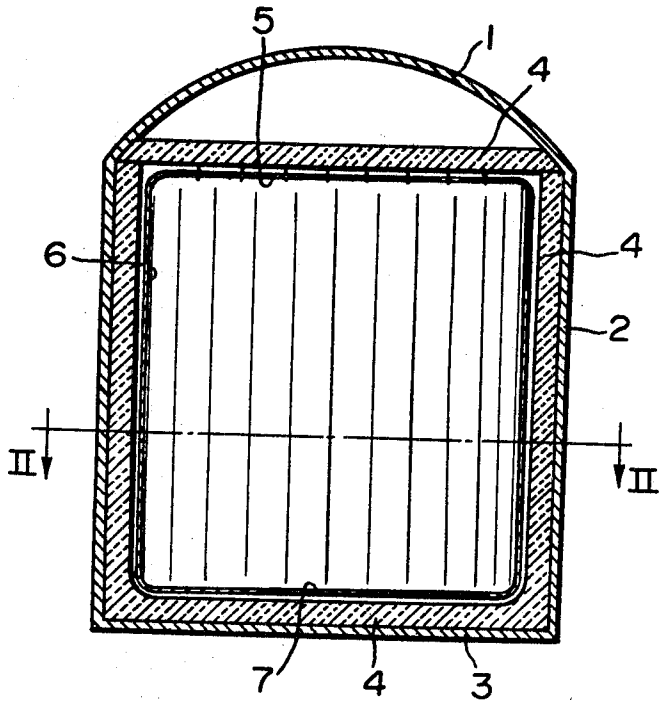


Fig. 1

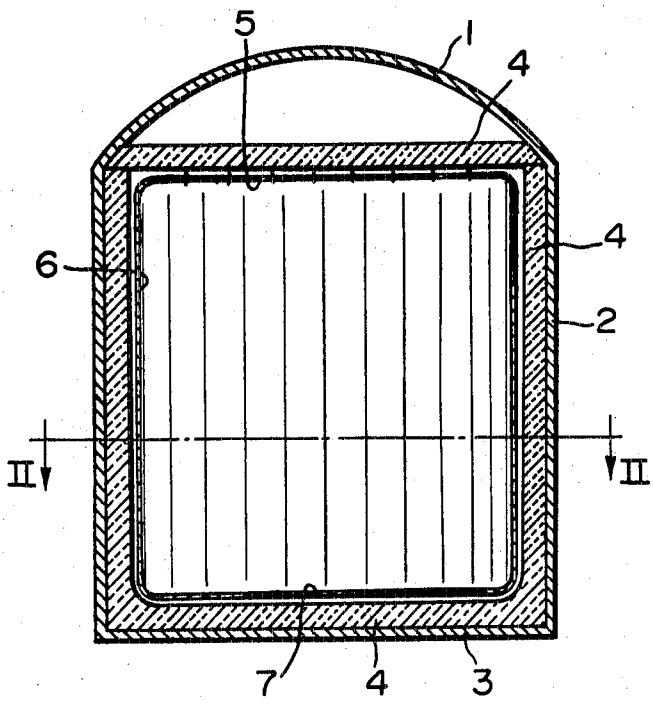
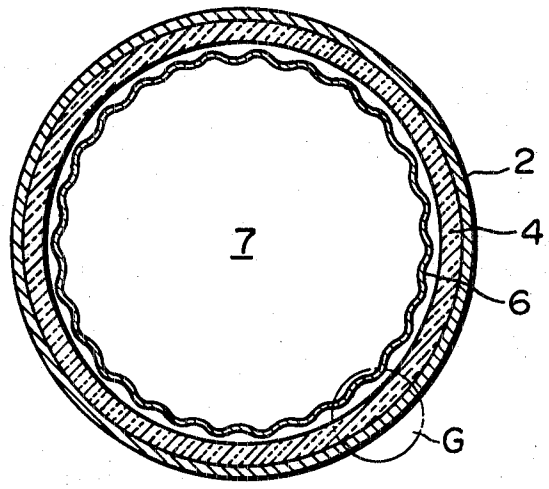


Fig 2



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Fig. 3

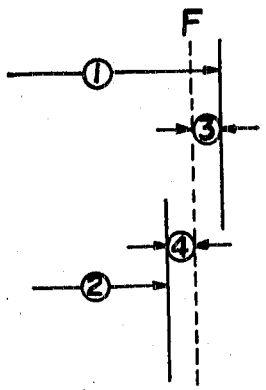


Fig. 4

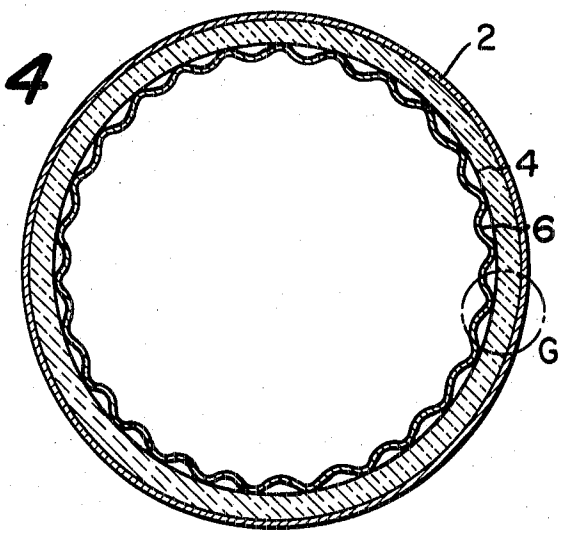
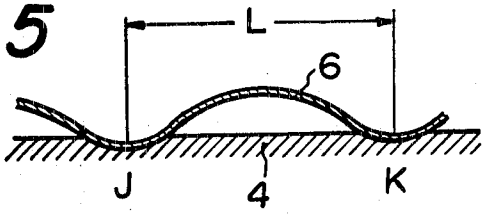


Fig. 5



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Fig. 6A

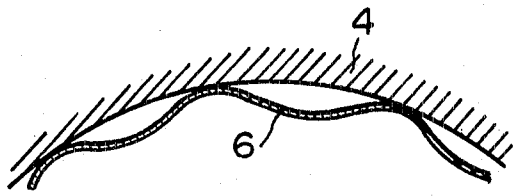


Fig. 6B

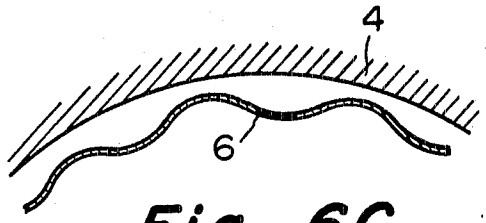


Fig. 6C

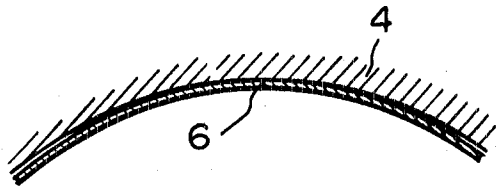
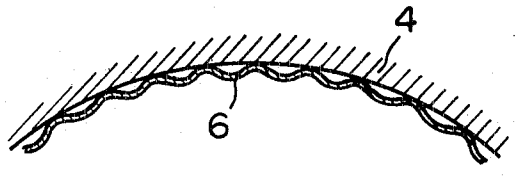


Fig. 6D



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TANK FOR USE IN STORING LOW TEMPERATURE LIQUEFIED GAS

This invention relates to tanks for use in storing low temperature liquefied gas such as low temperature liquefied natural gas, low temperature liquefied petroleum gas etc. and more particularly to an improved thin film type tank.

A thin film type tank comprises an outer vessel having a rigid construction, a heat insulating layer having a substantial resistance to compression resistant property and provided on the inside surface of the outer vessel and an inner vessel having a thin film construction and provided inside of the heat insulating layer, in which the inner vessel serves only to prevent leakage of the liquefied gas and the load resulting from the liquefied gas is supported through the heat insulating layer by the rigid outer vessel. Such an inner vessel comes into contact with the low temperature liquefied gas therefore it must be made of a material which does not have its flexibility altered by low temperatures, which materials are usually expensive. But, since the thickness of the inner vessel is small, it can be manufactured in a less expensive manner.

But, the inner vessel of the thin film type tank becomes not only contracted when exposed to the low temperature liquefied gas, but also elongated when it is subjected to the load resulting from the low temperature liquefied gas and brought into a close contact with the heat insulating layer. In this case, it is not desirable that the elongation of the inner vessel exceeds the elastic limit thereof. In order to avoid such undesirable elongation, a mechanism for allowing expansion and contraction of the inner vessel may be provided. But, such a mechanism affords the disadvantage that the construction of the inner vessel becomes complex. Moreover, the inner vessel made of thin film could not keep its configuration and hence must be supported at various points thereof by the heat insulating layer. These supporting points tend to prevent free movement of the inner vessel, with the result that dangerous stress occurs therein.

The principal object of the invention is to provide an improved thin film type tank and more particularly an inner vessel thereof without having the above mentioned disadvantages.

For a better understanding of the invention, reference is taken to the accompanying drawings, in which:

FIG. **1** is a vertical sectional view of a tank for use in storing low temperature liquefied gas according to the invention;

FIG. **2** is its transverse sectional view taken along the line II–II of FIG. **1**;

FIG. **3** diagrammatically illustrates the mutual relation between the dimensions of an inner vessel and those of an outer vessel;

FIG. **4** is a transverse sectional view similar to FIG. **2** and illustrating a state of the tank shown in FIG. **1**;

FIG. **5** is an enlarged view of the part surrounded by the circle G in FIG. **4**; and

FIG. **6A–6D** are enlarged views illustrating different states of the inner vessel including gently undulated camber according to the invention.

Referring now to FIG. **1**, the reference numeral **1** designates a roof of an outer vessel, **2** its sidewall and **3** a bottom plate thereof. **4** shows a heat insulating layer having a substantial resistance to compression, **5** a cover plate of an inner vessel, **6** its sidewall and **7** a bottom plate thereof.

In accordance with the invention the inner vessel is made of a thin film and constructed such that the load resulting from low temperature liquefied gas charged in the inner vessel is supported through the heat insulating layer **4** by the outer vessel. In the embodiment shown in the drawings, the inner vessel made of the thin film is so constructed that it is secured only at its cover plate **5** to the outer vessel inclusive of the heat insulating layer **4**, while the remaining parts of the inner vessel are not secured to the outer vessel.

Thus, the inner vessel becomes deformed when it is subjected to the load resulting from the low temperature liquefied gas. Such deformation of the inner vessel results in a so-called membrane force to be produced which propagates through the thin film. In a vertical sectional plane of the inner vessel, the membrane force moves towards that part of the inner vessel which is subjected in less extent to the load resulting from the low temperature liquefied gas. As the result, the deformations are concentrated on a rounded shoulder portion formed between the cover plate **5** and the sidewall **6** where no liquid load acts, and the membrane force acting upon the inner vessel in its vertical direction substantially disappears as the rounded shoulder portion is deformed. In a horizontal sectional plane of the inner vessel, however, the load resulting from the low temperature liquefied gas is evenly distributed and hence there occurs uniform hoop force. This hoop force acting upon the inner vessel in horizontal direction will now be described.

If the dimensions of the inner vessel at room temperature are made equal to those of the outer vessel, the inner vessel becomes contracted when it is exposed to the low temperature liquefied gas, while the outer vessel is not exposed to the low temperature liquefied gas so that it is not deformed whereby between the inner and outer vessels is formed a gap. Thus, the inner vessel is subjected to tensile stress resulting from the hoop force.

In general, if use is made of a thin film made of metals such as steel, aluminum, etc. as the inner vessel structural material, the inner vessel has to expand over its elastic limit in order to close the gap to be formed when exposed to the low temperature liquefied gas having a temperature less than about −40° C.

Thus, the above-mentioned design wherein the dimensions of the inner vessel at room temperature are made equal to those of the outer vessel results in considerable constructional disadvantage in that the inner vessel produces therein a stress exceeding its elastic limit.

In the present tank the peripheral dimensions of the material of the inner vessel at room temperature are made larger than the inner peripheral dimensions of the insulating layer of the outer vessel for the purpose of obviating the above mentioned disadvantage.

In principle, the inner vessel of the thin film-type tank should be formed into a liquidtight bag. It is desirable that no stress is applied to such a liquidtight bag even if it is subjected to the load resulting from the low temperature liquefied gas.

In FIG. **3** illustrating the mutual relation between the dimensions of the inner vessel and those of the outer vessel, if F designates a point at which no stress is applied, then the following relation is given by the equation:

$$① = ② + ③ + ④$$

where

① is the dimensions of the inner vessel at room temperature which are so designed that no stress is applied to it when it is subjected to the load resulting from the low temperature liquefied gas;

② the dimensions of the outer vessel;

③ the amount of thermal contraction of the inner vessel; and

④ the amount of deformation of the outer vessel when it is subjected to the load resulting from the low temperature liquefied gas.

That is, it is necessary to make the dimensions of the material of the inner vessel larger than those of the interior surface of the insulating layer of the outer vessel by taking into consideration the amount of contraction of the inner vessel and the amount of deformation of the outer vessel when they are subjected to the load resulting from the low temperature liquefied gas. In practice, however, it is almost impossible to bring the dimensions of the inner and outer vessels into coincidence with the above-mentioned no stress point F owing to the design and working accuracy. Different kinds of hoop force occur depending upon whether the dimensions of the inner vessel are smaller or larger than the no stress point F. That is:

1. there occurs tensile stress acting upon the inner vessel when its dimensions are smaller than the no stress point F;

2. there occurs compressive stress acting upon the inner vessel when its dimensions are a little larger than the no stress point F; and
3. there occurs compressive bending stress acting upon the inner vessel when its dimensions are considerably larger than the no stress point F.

When there occur the tensile stress and compressive stress acting upon the inner vessel as in the above mentioned cases **1** and **2** the allowable strain is about 0.2 percent for the design within the elastic limit of the inner vessel made of steel, aluminum etc. If this strain becomes more than about 0.2 percent there occurs plastic deformation of the inner vessel. In order to prevent occurrence of such plastic deformation of the inner vessel it is necessary to make the accuracy of design and working less than 0.2 percent. But, as above mentioned it is extremely difficult to make the accuracy of design and working less than 0.2 percent.

In general, when the thin film inner vessel is of welded construction, the film must have a substantial thickness and hence have a certain bending rigidity. Therefore, if the dimensions of the material of the inner vessel are made considerably larger than the no stress point F as in the above-mentioned case **3**, the excess portion of the inner vessel which is larger than the no stress point F is buckled to form regular waves as shown in FIGS. **4** and **5** when the inner vessel is exposed to the low temperature liquefied gas.

The shape and number of these waves are determined by the dimensions of the inner vessel, the amount of that excess portion of the inner vessel which is larger than the no stress point F, the modulus of elasticity of the film, the thickness of the film, the modulus of elasticity of the heat insulating layer adapted to support the inner vessel and the load resulting from the low temperature liquefied gas.

The number of these waves changes in dependence on the load resulting from the low temperature liquefied gas. If the load becomes increased, each of these waves becomes small to increase the number of waves.

The load acting upon these waves is considered to act upon a curved beam having a length L and supported at both ends J and K of each wave as shown in FIG. **5**.

Thus, the load resulting from the low temperature liquefied gas is supported by the curved beam so that allowable excess length of the inner vessel that is larger than the no stress point F is determined by the strength of the curved beam. The amount of such allowable excess length of the inner vessel is determined in dependence on the above mentioned various conditions and is larger than the allowable strain of the inner vessel when it is subjected to the tensile stress and compressive stress as described with reference to the above mentioned cases **1** and **2**. Particularly, when the supporting points J and K are located on an elastic heat insulating layer having a comparatively small modulus of elasticity (Young's modulus), the compressive bending stress becomes relatively small.

As an example, in a tank having an inner diameter of 20 mm. is enclosed an inner vessel made of aluminum film having a thickness of 3 mm. and this inner vessel is supported by a rigid heat insulating layer. The allowable rate of the excess length of the inner vessel is about 0.6 percent for the design within the elastic limit of the inner vessel of aluminum film, when it is subjected to the load resulting from the low temperature liquefied gas whose value is 0.6 Kg./cm^2.

In other words, the allowable strain for the case **3** is about three times larger than that for the cases **1** and **2**.

As seen from the above, it is preferable to make the dimensions of the material of the inner vessel a little larger than the no stress point F.

When the inner vessel is assembled in the outer vessel at room temperature, even in the case **1**, the dimensions of the sheet material of the inner vessel are made larger than those of the inner surface of the insulation layer of the outer vessel so that in the cases **2** and **3** the dimensions of the material of the inner vessel have to be made considerably larger than those of said inner surface of the insulating layer of the outer vessel.

That portion of the inner vessel which is larger than the outer vessel must be enclosed as corrugations in the outer vessel and these corrugations should disappear when the inner vessel is subjected to the low temperature and load resulting from the low temperature liquefied gas. Conventional flexible couplings could not be used as means for attaining such object instead of using the corrugations. It is preferable that these corrugations are regularly distributed and elastically restored to their original shape when the load is removed.

Experimental tests have yielded the result that the above mentioned requirements can be satisfied by using cambers **6** gently undulated as shown in FIGS. **6A—6D**.

FIG. **6A** shows the mutual relation between the inner and outer vessels in which the bottom of each camber **6** is in contact with the outer vessel, while the top of each camber **6** is located inside the outer vessel. If the inner vessel is exposed to the low temperature liquefied gas, the inner vessel contracts and is moved inwards and separated from the outer vessel as shown in FIG. **6B**. At the same time, if the inner vessel is subjected to the load resulting from the low temperature liquefied gas, the inner vessel is urged against the outer vessel whereby the cambers **6** disappear and are positioned at the above mentioned no stress point F as shown in FIG. **6C**. If the dimensions of the inner vessel are considerably larger than the no stress point F, then that surplus portion of the inner vessel which is larger than the no stress point F is yielded into a number of buckled waves as shown in FIG. **6D**. The shape of these buckled waves are not dependent upon the cambers shown in FIG. **6A**, but are determined by the above-mentioned various conditions.

While the invention has been explained with reference to the vertically cylindrical thin film type tank, it is a matter of course that the invention may also be applied to inboard rectangular thin film type tanks. Moreover, while the invention has been explained with reference to the inner vessel having no supported points in the horizontal section thereof, the invention may also be applied to rectangular tanks each provided at its center with a partition wall to which is secured the inner vessel. Thus, the invention is not limited to the shape of the tank and the presence or absence of points supporting the inner vessel in the horizontal section.

I claim:

1. A tank for use in storing low temperature liquefied gas comprising an outer vessel having a rigid construction and lined with a heat insulating layer having substantial resistance to compression, and an inner membrane vessel of a thin film type provided in said outer vessel, said inner membrane vessel including a sidewall having a plurality of vertically extending, circumferentially spaced corrugation means such that, at ambient temperature and under no load the peripheral dimension of the material of said inner membrane vessel is greater than the inner periphery of said heat insulating layer, said corrugation means being so gently undulated that when under load at low temperature said corrugation means tend to be flattened out and then said sidewall of said inner membrane vessel is buckled into a number of gently undulating waves which are of a different frequency than that of the initial corrugation means under the influence of compressive stress whereby the lateral stress to which said sidewall is subjected becomes substantially compressive or compressive and bending.

2. A tank for use in storing low temperature liquefied gas as claimed in claim **1** wherein said heat insulating layer has a comparatively small modulus of elasticity relative to the modulus of elasticity of the material of the membrane vessel thereby causing said compressive bending stress to be reduced.

3. A tank for use in storing low temperature liquefied gas as claimed in claim **1** wherein said inner membrane vessel includes a cover plate, rounded shoulder portions formed between said cover plate and said sidewall of said inner membrane vessel, the deformation of said inner membrane vessel at its vertical sectional plane produced when it is subjected to the load resulting from the low temperature liquefied gas being absorbed by said rounded shoulder portions.