Jan. 13, 1970 J. J. CLOSNER 3,488,972

CRYOGENIC STORAGE STRUCTURE

Filed Sept. 6, 1967 5 Sheets-Sheet 1

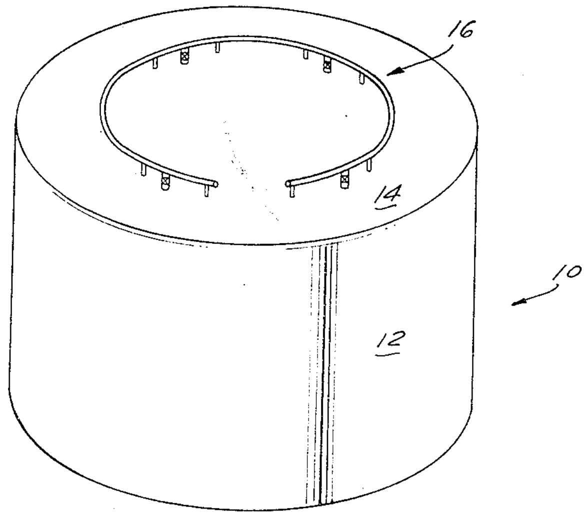
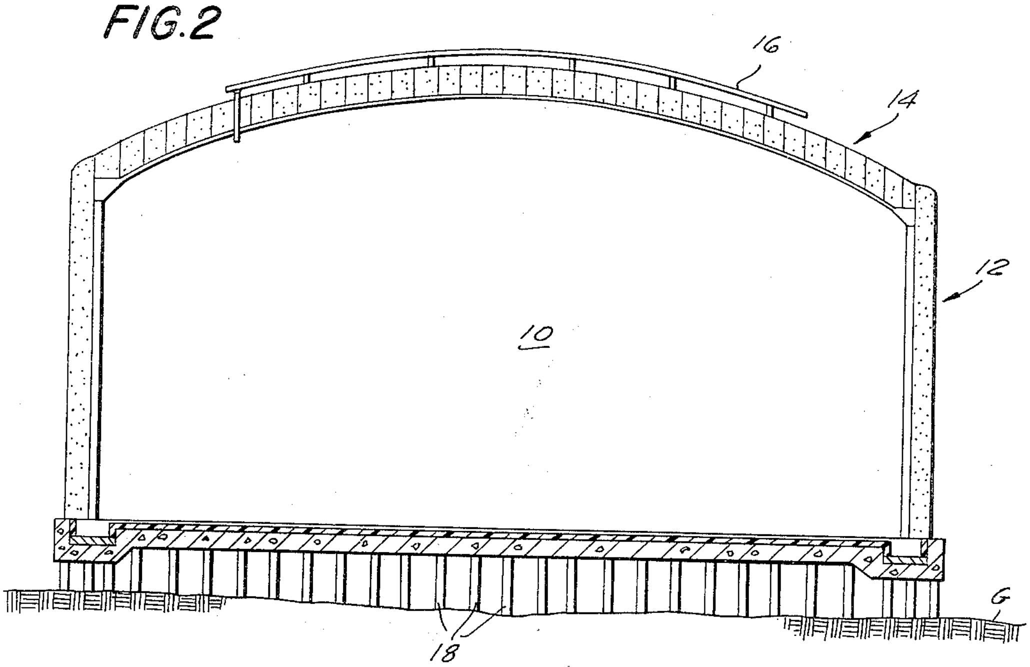


FIG. 1

FIG. 2



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CRYOGENIC STORAGE STRUCTURE

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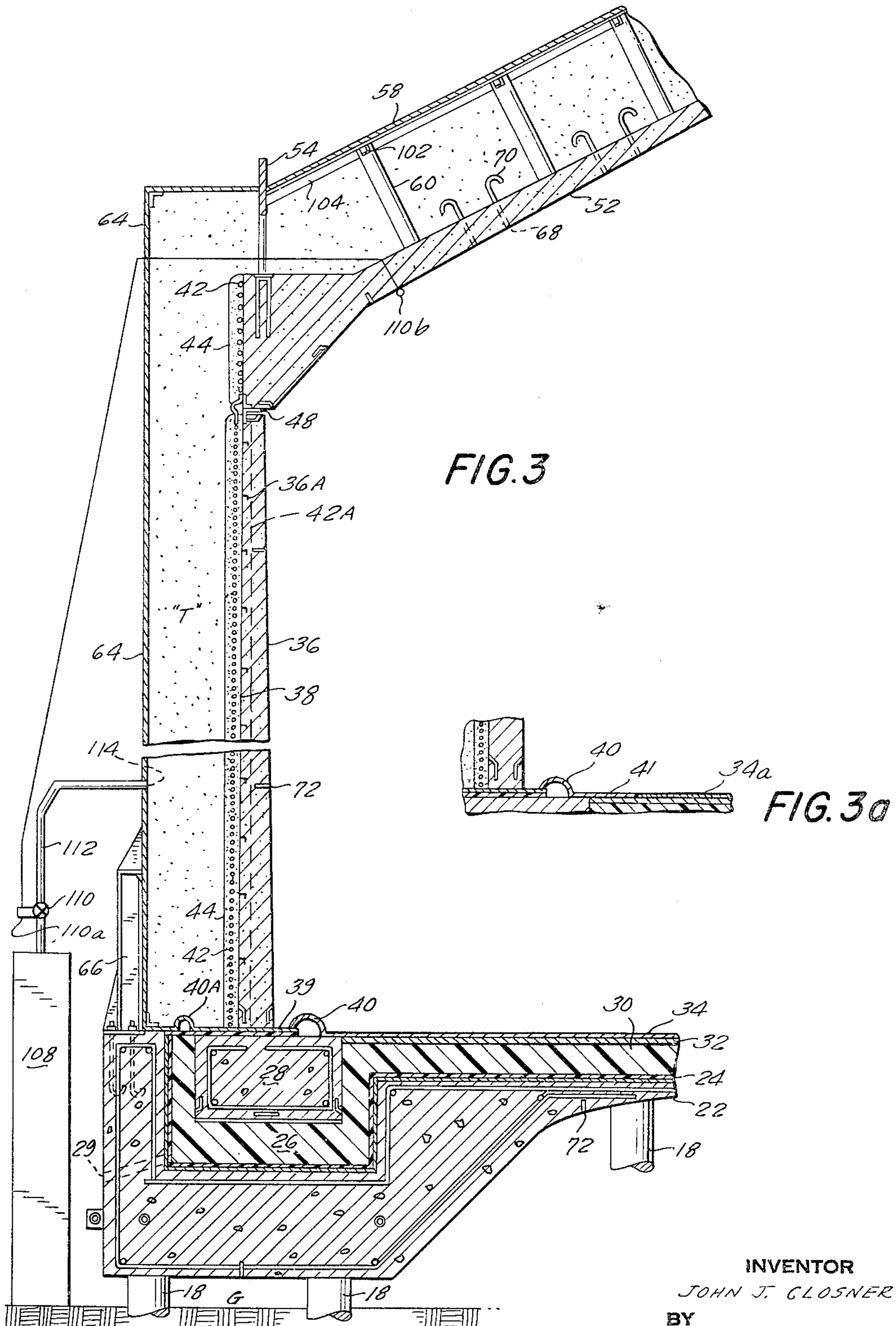

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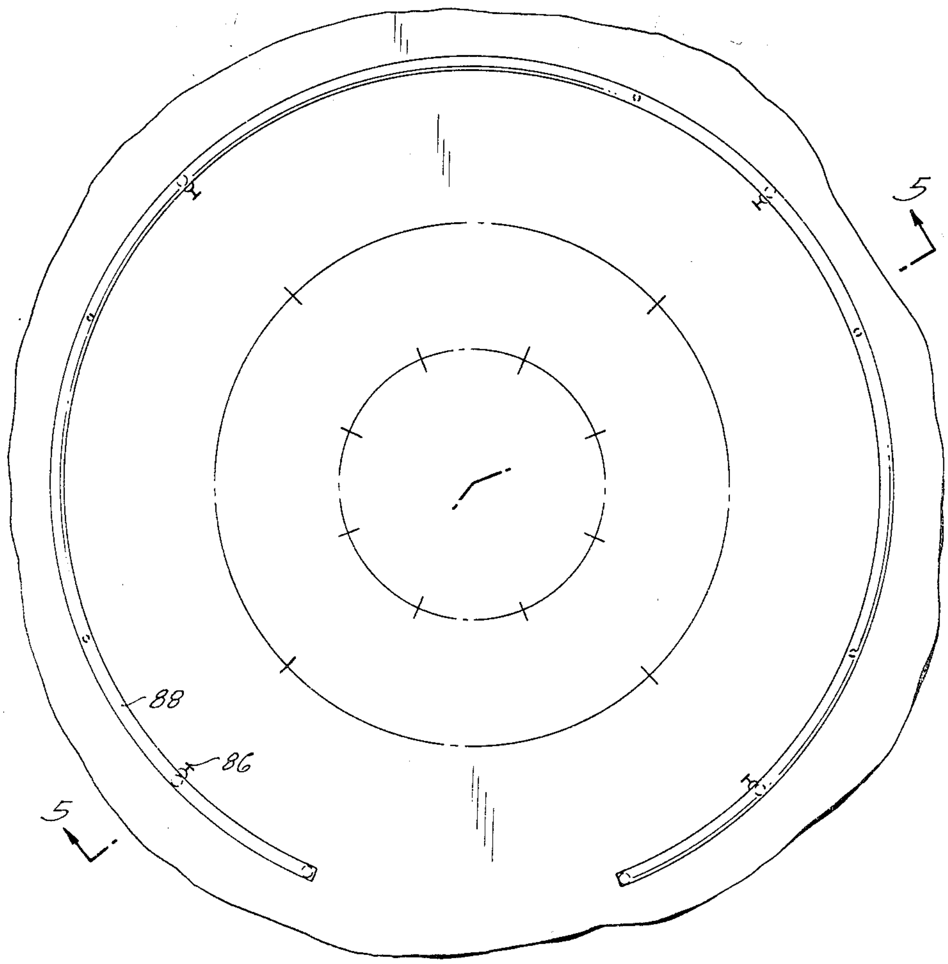

FIG. 4

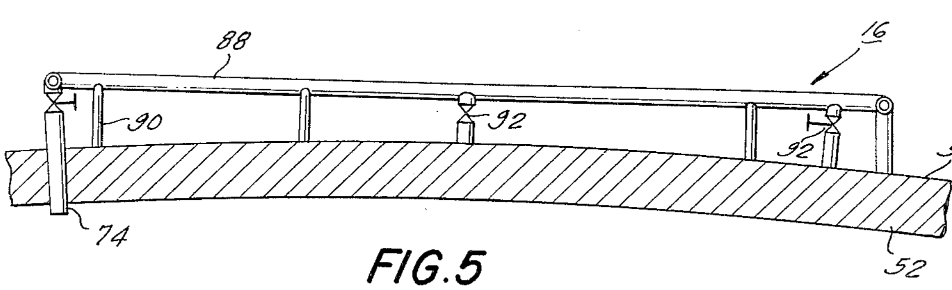

FIG. 5

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CRYOGENIC STORAGE STRUCTURE

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FIG. 6

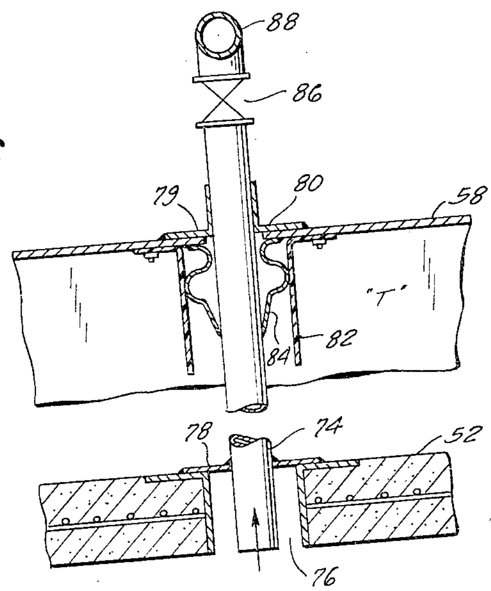

FIG. 7

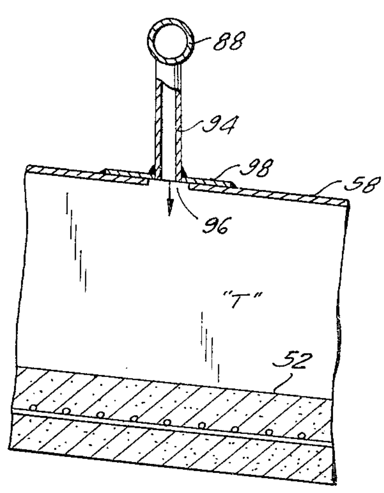

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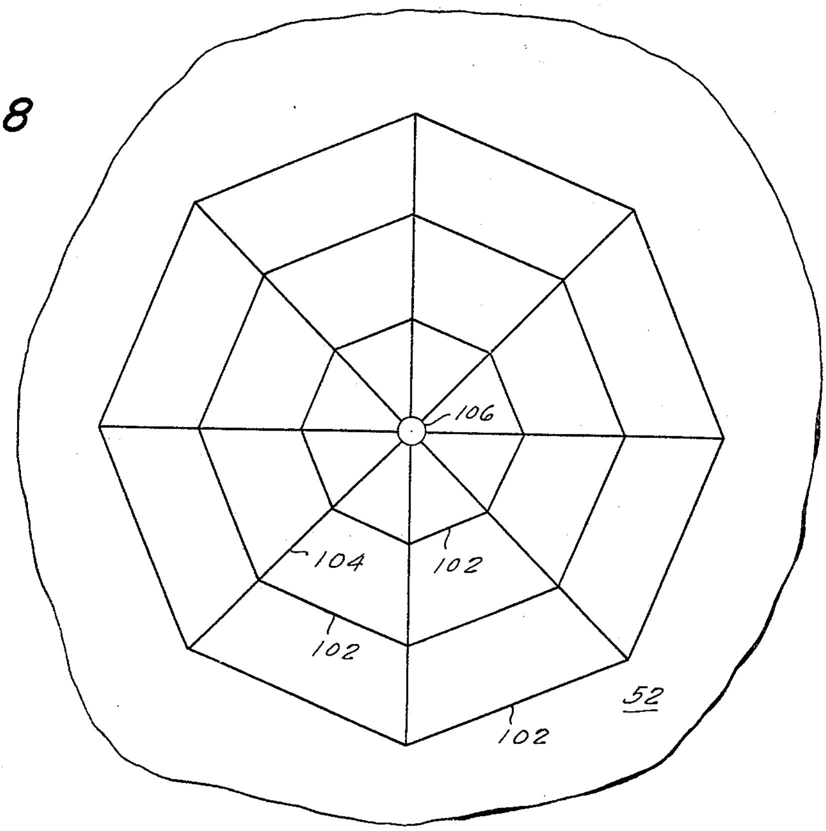
FIG. 8



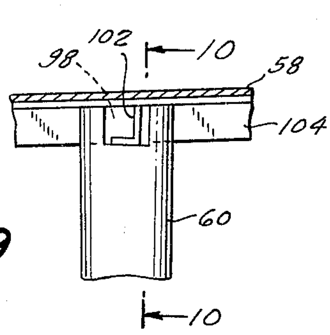


FIG. 9

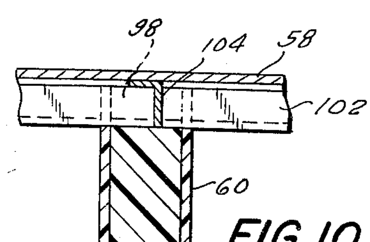


FIG. 10

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United States Patent Office 3,488,972
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3,488,972

CRYOGENIC STORAGE STRUCTURE

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Filed Sept. 6, 1967, Ser. No. 666,552
Int. Cl. F25d 23/12; E01b 3/04
U.S. Cl. 62—45 12 Claims

ABSTRACT OF THE DISCLOSURE

A cryogenic storage tank made of prestressed concrete having a dual roof system wherein pressure within the tank and pressure on the outer surface of the inner roof are maintained in substantial equilibrium to reduce the size and reinforcement of the roof, and carbon steel barriers are maintained in compression to avoid brittle fracture.

The present invention relates to the storing of liquified gases and more particularly to structures for containing the gases.

Many gases, such as natural gas, oxygen, nitrogen and the like are economically stored at temperatures far below the usual ambient temperatures so that they may be kept in liquid condition. When these gases are liquified they are in a cryogenic state and are known commonly as cryogenic liquids. Cryogenic liquids are stored at essentially atmospheric pressure but at extremely low temperatures, such as about −260° F. for liquified natural gas. The proper storage temperatures for different gases will vary, but they are well known.

In recent years there has been considerable activity to devise means and structures for storing liquified gases. This has been particularly so with the storing of natural gas. In many places there is a seasonal demand for natural gas for use as a heating fuel. During the period of great demand the supply and distribution system from the supply wells is obviously under a very heavy load. Also, during the non-heavy demand season the supply and distribution system is normally only partially used. In order to reduce the size of the gas transmission system it has been found feasible to stock pile liquified gases for use during the peak demand time, thus making greater use of the supply system.

Accordingly, there have been recent improvements in storage facilities for such gases. Storage structures which are useful for this purpose are shown and described in U.S. Patent No. 3,092,933, issued June 11, 1963 and in U.S. Patent No. 2,777,295, issued Jan. 15, 1957.

As shown in U.S. Patent No. 3,092,933 prestressed concrete structures may be used for the storage of cryogenic liquids. With prestressed concrete tanks, a roof system of the concrete dome type may advantageously be used. However, it has been found that vapor or internal pressure builds up within a tank and causes tensile stresses within the dome roof systems. As the tank pressure increases, it must be relieved or resisted to prevent possible damage to the roof system. A solution suggested heretofore has been to counteract the internal pressures within the tank by applying more concrete onto the dome roof and thus increase the dead load of the roof system to balance or counteract the internal pressure. However, the increased dead load of the roof system also creates severe stresses at the peripheral edge of the roof and bending in the shell of the dome. The increased dead load increases the horizontal thrust at the edge of the dome and also requires an increase in load capacity of the tank foundation as well as the dome ring support.

Accordingly, it is an object of the present invention to provide a storage system wherein a tank with a dual dome roof also has means for venting or balancing the

pressure of the tank to relieve internal pressure against the inner roof. It is another object to provide a system wherein the vapor which is relieved from within the tank may be used to blanket insulation materials which may be positioned between the dual dome roof, and, if desired, the insulation about the tank wall.

In the specification and the accompanying drawing, an embodiment of the present invention for the storage of liquified gases and the venting of tanks is shown. This embodiment is not to be construed as limiting the invention but rather it is for the purpose of informing those skilled in the art so that they may practice the invention in many embodiments and within the spirit and scope of the claims which are set forth hereinafter.

In the drawings:

FIGURE 1 is a perspective view of a cryogenic storage tank in accordance with the present invention;

FIGURE 2 is a sectional side view of the tank of FIGURE 1;

FIGURE 3 is an enlarged, partially fragmentary, sectional side view of the tank wall, floor and dome of FIGURE 2;

FIGURE 3*a* is an enlarged, partially fragmentary, sectional side view of the tank wall and floor of FIGURE 3 showing an alternate expansion joint and floor liner arrangement;

FIGURE 4 is a partially fragmentary top view of a dome of the tank of FIGURE 1 showing the tank pressure equalizing system;

FIGURE 5 is a partially fragmentary side schematic view of the tank pressure equalizing system;

FIGURE 6 is a partially fragmentary and schematic sectional side view of the inlet end of the tank pressure equalizing system;

FIGURE 7 is a partially fragmentary and schematic sectional side view of the outlet end of the tank pressure equalizing system;

FIGURE 8 is a schematic view of the shell roof bracing system;

FIGURE 9 is a partially fragmentary side view of the support members for the bracing system; and

FIGURE 10 is a partially fragmentary view of the support of FIGURE 9 taken in the direction of lines **10—10**.

Referring to the drawings and to FIGURE 1 in particular, a tank **10** in accordance with the present invention is shown. The tank **10** is comprised of a cylindrical side wall **12**, a dome roof construction **14** and a pressure equalizing system **16**. One of the functions of the pressure equalizing system is the prevention of pressure build-up in the tool storage system of the tank. The operation and advantages of a pressure equalizing system in cryogenic tank storage will be described in greater detail hereafter. However, it should be noted at this time that the pressure equalizing system **16** controls the pressure build-up beneath the dome roof and helps to equalize it with the pressure which exists in the insulation space which is found on the other side of an inner dome roof member.

As shown in FIGURES 2 and 3 in particular, further details of the tank structure are shown. In FIGURE 2 the illustrated tank **10** is built above grade or the ground line G. In order to support the tank, a series of pilings **18** are driven in accordance with well-known practice. On top of the pilings **18** a wall foundation **20** and a floor **22** are placed. Over the foundation **20** and the floor **22** a moisture barrier **24** is laid, the moisture barrier **24** being of any desirable selected type. A suitable moisture barrier is a laminate of aluminum foil sandwiched between layers of polypropylene.

This laminate may also be placed over a layer of roofing felt of **15** pound weight. To insulate the interior of the tank from the ambient atmosphere outside the foundation and the floor, suitable insulation is preferably provided over the moisture barrier **24**. Accordingly, a wall supporting insulation element **26** is provided in a recess in the foundation **20**. The insulation must support a substantial load from the side wall in addition to having the property of not providing thermal transfer. Foamed glass is suitable for this purpose.

A wall footing **28** made of high strength concrete and reinforced with steel rods in a conventional manner is placed on top of the insulation **26**. The wall footing **28** is the main support for the principal portion of the wall system **12**, and a weep hole **29** is provided to remove any moisture which may accumulate beneath it.

Adjacent to the wall footing **28** is an insulation layer **30** overlying the floor foundation **22**. The insulation layer **30** is also positioned over the moisture barrier **24**. Foamed urethane is a suitable material for the layer **30**.

As shown in FIGURE 3 a thin protective layer **32** is deposited on top of the floor insulation **30**. The layer may be of any suitable material such as plywood or lean concrete—lean concrete being shown in the illustrated embodiment. Over the protective layer **32** is placed an inner floor liner or barrier **34**, the liner **34** being preferably made of 9% nickel steel. It is the liner **34** which is in intimate contact with liquified gas contained within the tank **10** and for this reason the nickel steel heretofore has been selected since it is highly resistant to brittle fracture at extremely low temperatures.

The side wall **12** is actually a three-part combination including (1) an inner concrete core wall **36**, (2) a wall liner **38** and (3) a layer of prestressing tendons **42**. The core wall **36** is the main vertical structural member for containing the liquified gas within the tank **10** and on the outer surface of the core wall **36** a liner **38** is provided, and anchored to the outer face of the core wall with suitable embedded anchor studs **36*a***. The core wall is prestressed vertically by pretensioned or posttensioned prestressing reinforcement depending on whether the core wall is made of precast sections or cast in situ. The anchor studs **36*a*** insure that a portion of the vertical prestressing force provided by tendons **42*a*** pass to the liner **36** thus placing it in vertical compression. The prestressing tendons **42** are wound about the core wall **12** and the liner **38**, and stressed to provide the desired circumferential compression in the wall **36** and the liner **38**, and then covered with a protective coating of suitable material, usually mortar, in the form of a covercoat **44**. This type of wall construction is set forth and discussed in detail in U.S. Patent No. 3,092,933, issued June 11, 1963 to Closner et al.

The liner **38** acts as a liquid and vapor proof barrier and may be made of carbon steel since it is composite with the prestressed core wall **36** and in compression, both vertically and circumferentially; therefore, it is not subject to brittle fracture by the low temperature.

The wall liner **38** is advantageously connected to the floor liner **34** so that a continuous moisture and vapor proof barrier is provided for containing the liquified gas. Between the floor liner **34** and the wall liner **38** an expansion loop **40** of stainless steel is also included to compensate for the expansion and contraction of the floor liner **34**.

Passing under the core wall **36** and connected to the expansion loop **40** and the liner **38** is a plate member **39** which is also preferably made of stainless steel or 9% nickel steel since it is at least partially exposed to the low temperature of the liquified gas.

Brittle fracture may occur with steel when the following conditions are present: (1) a temperature that is below the nil ductility temperature of the steel; (2) the existence of a notch connection or construction such as with a welded joint; and (3) a developed tensile strength above approximately 10% of the ultimate strength of carbon steel.

As stated previously, the liner **38** is advantageously kept in compression and therefore not subject to brittle fracture.

In FIGURE 3*a* a construction is shown wherein carbon steel may be utilized for a substantial portion of the floor liner. In that construction the floor liner **34*a*** is separated from, but connected to, the expansion loop **40** by a flat ring **41** which is advantageously made of 9% nickel steel or stainless steel. The width of the ring **41** need only be sufficient to insure that any tensile stress developed at the joint between loop **40** and ring **41** is absorbed by the ring. Accordingly, with a tank having a diameter of 250 feet, a ring **41** having a width of about twelve inches is sufficient to absorb any such stresses.

Since the liner **34*a*** is free to move relative to the protective layer **32**, and since the maximum contraction of the liner **34*a*** occurs when the storage container is cooled down to near its operating temperature with vapor and no liquid load is present on the liner to restrict movement, the liner working with the expansion loop **40** is free to contract without significant restraint and, thus, is not subjected to a tensile stress about 10% of its ultimate strength.

At the top of the core wall **36** a sliding joint **46** comprised of joint plates **48** provides a seat for the dome **14**. The dome **14** is made of reinforced concrete and includes a haunch portion **50** at its peripheral edge and a central roof portion **52**. The design and construction of domes having haunch and roof portions are well known to those skilled in the art. The dome must be designed and constructed to have sufficient strength to withstand the internal pressures which build up within the tank due to boil off, i.e. evaporation of the liquified gas stored therein, as well as the strength to take care of external loads.

Boil off occurs at the upper surface of the liquid where it is exposed to the vapor in the tank. It is kept to a minimum by means of insulation provided around the tank. If there is a too rapid boil off of the liquified gas into the gaseous state, perhaps caused by an external fire, the internal pressure against the dome **14** will be very large. Pressure relief devices provide for venting such too rapid boil off to the atmosphere.

Heretofore, the basic means of handling normal internal pressure has been to increase the strength of the inner dome. The problem with increasing the strength of the inner dome is that in order to do this the dead load and reinforcement of it must also be increased and then added strength must be built into it to take care of the dead load. As a result, an unwieldy and very expensive inner dome structure must result if proper precaution is to be taken against excessive internal pressure build-up.

Surrounding the core wall **36**, the haunch **50** and the roof portion **52** is a large mass of a thermal insulation T. A suitable insulation material is of the granular type, such as perlite. Other insulation materials which may be used are vermiculite, chopped or shredded polystyrene foam, polyurethane foam (which may be foamed in place if desired) and glass wool.

In order to maintain the insulation T in place, an outer shell is provided around the side wall **12** and the dome **14** but spaced therefrom. Around the periphery of the tank a compression ring **54** to withstand the pressure on the interior of the roof **58** is located and supported on members **56** which are mounted on the haunch **50**. Attached to the compression ring **54** is an outer roof **58**. Supporting the outer roof **58** and spacing it from the inner roof portion **52** are a series of spacers **62**. Concentrically located outside of the core wall **36** is a shell wall **64** which is made of steel. The shell wall **64** is also connected to the compression ring **54** and with the outer roof **58** combines to form the outer shell of the tank **10**. If desired, the compression ring **54** may be placed at the top of the shell wall **64**.

The insulation material T is contained in the space formed by the core wall **36**, the outer wall **64**, the roof portion **52** and the outer steel roof **58**.

An anchor **66** is provided in the foundation **20** to hold the outer shell wall **64** in place.

The outer shell wall **64** is connected to the tank floor system **34** by means of expansion loops **40** and **40***a*.

The outer roof **58** and the outer shell wall **64** may be made of any suitable steel sheet material. No exceptional thermal precautions must necessarily be taken with the outer wall and roof since they are not in contact with the cold liquified gas. The compression ring **54** is preferably made of carbon steel for economy reasons since it is in a warm environment and not subject to brittle fracture. The supports **56** are preferably made of a brittle fracture resistant material, such as 9% nickel steel since they are in contact with the haunch **50** and may be subjected to extremely low temperatures at the point of contact with the haunch. The members **56** are advantageously arranged in alternate bracing configurations and angles are satisfactory for this purpose.

The roof supports **60** which are also in contact with a concrete surface which may also be subjected to low temperatures. Rather than use expensive 9% nickel steel for this purpose, reinforced fiber pipe such as fiber glass reinforced polyester is suitable. In addition to the polyester pipe, cement asbestos or plywood supports may also be used. The roof supports while having good support strength also advantageously have sufficient flexibility to permit movement of the steel roof. To permit the roof shell **58** to expand and contract as necessary, the support members **60** are preferably not connected to the roof so that the support members merely act as unconnected supports for the roof system.

In order to blanket the insulation material T with a gas free of moisture, it has been found that the boil off of gas from the liquified gas contained within the tank may be used for this purpose. To accomplish this, a series of openings **68** may be provided in the concrete roof portion **52**. These openings **68** are fitted with goosenecks **70** which permit the boil off gas to penetrate into the insulation T without the problem of the insulation filling the goosenecks and eventually the openings **68**. As the internal pressure builds up within the tank T the pressure on each side of the roof portion **52** will be balanced since the opening **68** and the gooseneck **70** permit the gas within the tank to flow into the insulation space and through the insulation to the inner side of the outer roof **58**.

As shown in FIGURES 4, 5, 6 and 7 in particular, a more detailed arrangement for equalizing the pressure within the tank is illustrated.

The pressure equalizing system **16** provides a long gas travel of the boil off gas and resulting positive heating of the gas in the ambient temperature without the necessity of elaborate pumping or gas moving equipment.

The pressure equalizing system **16** includes a tank gas outlet pipe **74** which extends from the interior of the tank **10** through an opening **76** in the concrete roof portion **52**. A plate **78** is provided about the outlet pipe **74** and connected to the roof portion **52** and the pipe **74** so that a positive seal is made at the outer extent of the opening **76**. The pipe **74** extends upwardly through the insulation T and through an opening **79** in the shell roof portion **58**. A seal member **80** is provided about the opening **79** and connected to the roof portion **58** and the outlet pipe **74**. Also surrounding the pipe **74** is a fiber glass sleeve **82**. Contained within the fiber glass sleeve **82** is a stainless steel bellows **84** which is connected to the outlet pipe **74** and the steel outer shell **58**. The purpose of the stainless steel bellows **84** is to provide for any expansion or deflection of the outlet pipe **74** and still maintain the seal in the space filled with the insulation T.

After the outlet pipe **74** passes into the ambient atmosphere beyond the outer shell **58** it is provided with an outlet valve **86** which is preferably made of stainless steel. The outlet valve **86** acts to control the flow of gas from the interior of the tank **10** and through the pressure equalizing system. Connected to the valve **86** is a gas travel pipe **88** which is of an arcuate shape and is positioned so that it is in the ambient atmosphere and on the outer surface of the shell **58**. Supporting the travel pipe **88** are a series of supports **90** which are mounted on the shell **58**. At various locations along the travel pipe **88** of a series of return valves **92** are provided. The return valves **92** are also preferably of stainless steel and are connected to return pipe conduits **94**. The return pipe conduits **94** communicate with an opening **96** in the outer shell **58**.

By the time the boil off gas has traveled through the extent of the pressure equalizing system **16** and returned by means of the return pipe **94** to the space inside the shell **58** which is filled with the insulation T, it has been heated up to a temperature approaching that of ambient outside the tank. The heating up to ambient temperature is advantageous since the outer steel shell **58** is made of carbon steel and would be subjected to possible brittle fracture if it had impinged upon it cold boil off gas. However, by means of the arrangement shown in FIGURES 4, 5, 6 and 7 in particular, the gas deposited through the return pipe **94** is of high enough temperature so that the possibility of brittle fracture is substantially eliminated.

For economy sake the shell roof **58** is of relatively thin steel sheet and it is exposed to the elements of nature such as wind, rain and perhaps snow. Therefore, it is preferably stabilized against external forces. As shown in FIGURES 8, 9 and 10 a bracing system may be incorporated for use in conjunction with the supports **60** to stabilize the shell roof **58** against the external forces. The bracing system is preferably positioned between the upper portion of the supports **60** and the shell roof **58**.

To accommodate the bracing system, cut outs **98** are provided in the upper end of the supports **60**. A series of angles **102** are concentrically located in the cut outs **98** in concurrent fashion beneath the roof **58**. The individual angles **102**, which in the illustration of FIGURE 8 are chords, are joined together to make several complete concentric units. The angles **104** comprise a series of radial aligned supports connected at **100** to the angles **102**. The angles **104** are joined at their center intersection by a splice plate **106**. On top of the angles **102** and **104** the shell roof **58** is placed.

Since the shell roof **58** rests on and may be connected to the grid system formed by the angles **102** and **104** or restricted at points of support so that it is free to move radially with respect to the center of the spherical segment but not circumferentially, it is braced against external loads such as wind and the like. By limiting the size of the cut outs **98** there is a restriction to the tangential movement of the roof **58** and thus the entire dome shell is strengthened against the external forces. The amount of restraint exercised by the grid system is determined by the limits of the vertical supports and the size of the cut outs **98**.

As shown in FIGURE 3, a gas pressure controller **108** may be used if desired to maintain the desired pressure in the insulation space. If the controller **108** is utilized, the openings and communication between the interior of the tank and the insulation space may be eliminated. In order to substantially equalize the pressure between the tank and insulation space, the valve **110** is controlled by pressure controller **110***a* actuated by pressure sensing means **110***b* which is connected to the tank proper.

With the controller **108** a valve **110** is provided to shut off the flow of gas into the space through the pipe **112** which is connected to an opening **114** in the wall **64**.

When the controller **108** is used, an inert gas, such as nitrogen, is pumped into the insulation space to blanket the insulation. As pressure builds within the tank and against the inner dome **52**, the controller increases the pressure against the outer surface of the dome **52** to counteract the buildup within the tank. In such a system the pressures on each side of the inner dome 52 are kept substantially equal.

By "substantially equal" is meant that the pressure differential in favor of the internal pressure is preferably not substantially greater than the dead weight of the inner dome 52. Normally, this differential would be expected to be about 2–3 inches of water.

It will be appreciated that the present invention provides means for maintaining equalized pressure on the inner dome roof of a cryogenic storage structure. Such a system is also desirable in respect to the sidewall system. However, such control of sidewall gas or vapor pressure will not normally come into consideration as the liquid level of the liquified gas will generally rise to the upper portion of the sidewall.

It is claimed:

1. A structure for storing liquified gases maintained at low temperature comprising a floor, a side wall and a roof system, said side wall including an interior prestressed concrete core wall connected to the floor and a moisture and vapor proof barrier substantially coextensive therewith, said roof system including a reinforced inner roof connected to and supported by said core wall and a second outer roof spaced from the inner roof to form an insulation space, said outer roof having compression means connected therewith said space containing insulation material of the type through which gas may pass, and gas connecting means between the interior of the structure and the insulation space whereby gas pressure on each side of the inner roof may be substantially equal.

2. A structure as defined in claim 1 and further including an outer shell wall spaced from the concrete core wall, said shell wall joined to the outer roof and insulation placed in the space formed by the inner core wall and the outer shell wall.

3. A structure as defined in claim 1 and further including spacer means for maintaining the outer roof spaced from the inner roof.

4. A structure as defined in claim 1 and further including spacer and support means for maintaining the outer roof spaced from the inner roof and supporting the outer roof against external forces.

5. A structure as defined in claim 4 wherein the spacer and support means includes a grid system of radially aligned members and concentric members underlying the inner roof, said grid system supported in place by spacer members mounted on the inner roof.

6. A structure as defined in claim 1 wherein said floor comprises an inner sheet member resistant to brittle fracture at low temperatures, an insulation layer supporting said sheet member, a moisture barrier underlying said insulation, and a reinforced support member beneath the moisture barrier.

7. A structure for storing liquified gases maintained at low temperatures comprising a floor, a side wall and a roof system; said side wall including an interior prestressed concrete core wall having a moisture and vapor proof barrier substantially coextensive therewith and an outer shell wall spaced from the concrete wall; said roof system including a reinforced inner roof connected to and supported by said core wall and a second outer roof supported and spaced from the inner roof by a grid system of radially aligned members and concentric members underlying the inner roof with said grid system supported in place by spacer members mounted on the inner roof; said floor comprising an inner sheet member resistant to brittle fracture at low temperatures, an insulation layer supporting said sheet member, a moisture barrier underlying said insulation, and a reinforced support member beneath the moisture barrier; insulation material of the type through which gas may pass in the space formed by the inner and outer walls and the inner and outer roofs; and gas connecting means between the interior of the structure and the insulation space whereby gas pressure on each side of the inner roof may be substantially equal.

8. A structure for storing liquified gases maintained at low temperature comprising a floor, a side wall and a roof system, said side wall including an interior prestressed concrete core wall connected to the floor and a moisture and vapor proof barrier substantially coextensive therewith, said roof system including a reinforced inner roof connected to said core wall and a second outer roof spaced from the inner roof to form an insulation space, said outer roof having compression means connected therewith, said space containing insulation material of the type through which gas may pass, and gas pressure control means for maintaining a gas pressure in the insulation space substantially equal to the gas pressure within the tank and against the inner roof.

9. A structure as defined in claim 1, and further including a mositure and vapor floor barrier substantially coextensive with the floor and placed thereon, said floor barrier having an inner portion of carbon steel and a peripheral portion made of a brittle fracture resistant steel, and an expansion loop connecting said peripheral portion to the wall barrier.

10. A structure as defined in claim 8 and further including a moisture and vapor floor barrier substantially coextensive with the floor and placed thereon, said floor barrier having an inner portion of carbon steel and a peripheral portion made of a brittle fracture resistant steel, and an expansion loop connecting said peripheral portion to the wall barrier.

11. A structure for storing liquified gases maintained at low temperatures comprising a floor, a sidewall and a roof system, said sidewall including an interior prestressed concrete core wall and a steel moisture and vapor proof barrier substantially coextensive therewith and maintained in a state of compression in two directions by prestressing tendons wrapped about the core wall to prestress said wall horizontally and vertically by vertical prestressing tendons in the core wall, a steel moisture and vapor proof floor barrier substantially coextensive with the floor and free to contract without restraint to prevent brittle fracture at low temperatures, and a brittle fracture resistant expansion loop connecting said barriers.

12. A structure for storing liquified gases maintained at low temperatures comprising a floor, a sidewall and a roof system, said sidewall including an interior prestressed concrete core wall and a steel moisture and vapor proof barrier substantially coextensive therewith and maintained in a state of compression in two directions by prestressing tendons wrapped about the core wall to prestress said wall horizontally and vertically by vertical prestressing tendons in the core wall and a steel moisture and vapor proof floor barrier substantially coextensive with the floor, the inner portion of said floor barrier being brittle fracture resistant steel, and a brittle fracture resistant expansion loop connecting said barriers.

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LLOYD L. KING, Primary Examiner

U.S. Cl. X.R.

61—.5; 62—260