

APPARATUS FOR GAS STORAGE AND TRANSPORT

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the priority of U.S. Provisional Patent Application No. 63/124,325 titled “APPARATUS FOR GAS STORAGE AND TRANSPORT,” filed
5 December 11, 2020, the contents of which are hereby incorporated by reference.

FIELD OF THE INVENTION

The invention relates to an apparatus and method for the storage and transport of fluids, i.e., gases and liquids, such as hydrogen and natural gas transport by ship or by barge.

BACKGROUND OF THE INVENTION

10 Hydrogen is becoming an important fuel to reduce carbon dioxide emissions. There are locations where hydrogen can be produced at a much lower cost than where the hydrogen is demanded. For example, Australia can produce hydrogen at a lower cost than Japan. This separation of low-cost supply from demand by a body of water creates a need for ships capable of transporting hydrogen. The large-scale transport of hydrogen by sea will be an
15 important part of the future hydrogen ecosystem just as natural gas transport by ship is a large part of the existing natural gas ecosystem.

There are known methods of transporting natural gas across bodies of water including for example, through subsea pipelines, by LNG ships as liquefied natural gas or by CNG ships as compressed natural gas (CNG). There are other known means, such as converting
20 the gas to gas hydrates or to a diesel-like liquid (GTL) and shipping the hydrates or GTL by ship. Currently, virtually all transport of natural gas across bodies of water is carried out by either subsea pipelines or LNG ships.

Hydrogen presents some unique challenges for large-scale shipment. Hydrogen is extremely light and requires either liquefaction or compression to increase its density for

shipping. Liquefaction requires the hydrogen to be cooled to about -253 degrees centigrade. This is much colder than required for liquifying natural gas and is near absolute zero (-273°C). This extremely cold temperature requires costly liquefaction processes and costly containment systems. Compression of hydrogen is well known and most hydrogen is

5 transported as compressed gas, not liquified. The containers for compressed hydrogen are typically either steel or composite. Steel containers are relatively less expensive than composite containers but are significantly heavier. For road transport the weight of the container is critically important but for ship transport the weight penalty for steel is less critical. One of the main concerns with shipping compressed hydrogen in steel is that the

10 hydrogen molecule is so small it can enter the steel structure and over time cause the steel to become less ductile. This process is known as embrittlement. There are established methods of preventing embrittlement such as keeping the stresses low or lining the steel with a material that is resistant to hydrogen embrittlement.

The terrestrial transport of compressed and liquified hydrogen by truck is well known.

15 There are existing hydrogen fuel stations, primarily for dedicated fleets of hydrogen fueled commercial vehicles. The large-scale transport of hydrogen by ship is not yet established but it is an emerging industry.

One of the major impediments to shipping compressed hydrogen by sea is the cost of a suitable hydrogen containment system that is suited to ship or barge transport. Thus, there

20 is an ongoing need to design storage systems for compressed hydrogen that can contain large quantities of hydrogen and that are particularly suited for installation on or within ships and barges in a way that reduces the overall cost of the compressed hydrogen (C-H₂) ship or barge. It is an object of the present invention to reduce the cost of ships or barges designed to carry compressed hydrogen and other gases.

A cost-effective hydrogen carrying ship would greatly enhance the economic feasibility of shipping large quantities of compressed hydrogen.

SUMMARY OF THE INVENTION

5 The invention relates particularly to the marine gas transportation of non-liquefied compressed hydrogen although it could be used to transport other gases. The invention is capable of carrying natural gases, pure gases, such as hydrogen, or a combination of liquids and gases, such as rich natural gases with heavier hydrocarbons being liquid. The invention can also carry a combination of liquids and gas such as oil and natural gas, e.g., well fluids.

10 In one embodiment, the invention of the application embodies large storage tank(s) contained within a hold of a ship or barge. A preferred storage system is particularly adapted for the transportation of large quantities of compressed fluids including mixtures of gases and liquids. It is beneficial to store the compressed fluid in a large tank to minimize the internal surfaces that would need to be protected from corrosive fluids and embrittlement from
15 gaseous hydrogen. The walls of a tank used to store high pressure fluids must become increasingly thick as the size of the tank increases. Also, a large thick-wall tank has to be supported and contained within the hull of the ship or barge. Mounting a large, heavy tank on the top deck of a barge or a ship may create stability concerns since a deck mounted heavy tank raises a center of gravity of the system. Therefore, this invention considers that the
20 cargo tank is enclosed within the hull of the ship or barge. High pressure tanks are typically cylindrical in cross-section because a cylinder has less maximum stress than a square or rectangular shape of the same volumetric dimensions.

 The largest possible cylindrical tank in a ship is bound by the ship dimensions. To allow a largest possible tank to be contained within the cargo area of the ship there can be no
25 transverse bulkheads. To construct such a large diameter cylinder from a single plate of steel

would require a plate thickness that would be exceedingly difficult to produce and to bend into a cylindrical shape. Therefore, two main technical issues that must be solved relate to:

1. How to design and construct a very thick wall tank using unconnected thin plates.
- 5 2. How to support very heavy large tank(s) efficiently within a vessel structure in such a way that prevents the tank expansion caused by pressurization from damaging the ship structure.

The invention of the application solves each of these technical issues in a novel way. Hereinafter the description will focus on a ship application to carry compressed hydrogen. However, the invention could also be employed to carry other gases or a mixture of gas and liquid. The tank of the invention may also be deployed within the hold of a barge or other floating structure.

In a preferred embodiment, the cargo area of a ship is divided into 2 long cargo areas separated by a double-walled longitudinal bulkhead. There are no transverse bulkheads in the cargo area. There is one large cargo tank situated in each of the two cargo holds. In another embodiment, a single tank is contained within a hull defining a single hold.

The tank is constructed of several unconnected layers, e.g., 3 to 10 layers. In the present invention, there is no need to ensure 100% metal to metal contact between layers. It is only important for the layers to be touching over most of the surface. The amount of contact achieved by simply placing one plate on top of the other is enough to ensure the stresses in all layers will be within the allowable limits. The invention of the application greatly simplifies the construction process and relies on plastic-elastic material properties to ensure that all layers work together to resist the stresses caused by the internal pressure.

One significant further advantage of a tank made from multiple discrete layers is that, should a crack form in one layer, it will not naturally proceed through to the adjacent layer.

This greatly improves the safety of the tank compared to a similar sized tank comprised of a single thick wall.

The innermost layer is designed to resist hydrogen embrittlement or corrosion caused by other gases. The material properties of this inner layer will be determined by the fluids to be contained in the cargo tanks. The subsequent layers are designed based on constructability and manufacturing capability. In one example, the proposed cargo is hydrogen. Therefore, an example first innermost layer is a stainless steel, aluminum or plastic layer capable of resisting hydrogen embrittlement. Subsequent layers could be made from a high strength carbon steel.

One serious technical challenge in constructing such a large tank with a series of nested thin layers is that the layers may sag under their own weight. In one embodiment, the sagging of the plates is prevented by welding the outermost layer to structure of the ship, such as the top deck girders of the ship. This supports the outermost layer and prevents it from sagging. Since the top layer does not sag the inner layers cannot deform and sag as the inner layers are nested within the outer layer whose geometry is constrained, i.e., the outer layer is prevented from sagging by being attached to the top deck.

Another technical challenge is to prevent the tank from damaging the ship hull as it expands during pressurization. To prevent this a gap is left between the side shell of the ship and the tank.

Another technical challenge is to develop a tank end or head that can be easily constructed. Typically, the heads of a pressure cylinder are either spherical or hemispherical. For a large diameter tank, the construction of such a head would be difficult and expensive. To overcome this challenge the tank ends or heads are constructed with conical sections allowing them to be constructed using single curvature plate in multiple layers. This greatly simplifies construction and reduces cost.

The preferred embodiment described below is a ship with a cargo hold separated by a longitudinal bulkhead into port and starboard cargo sections each with a single tank. For a smaller ship or barge it is possible to have a single cargo hold, not separated by a longitudinal bulkhead and one tank contained within the cargo hold.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side elevation view of a schematic of a ship containing tanks;

Figure 2 is a top plan view of a schematic of the ship of FIG. 1 showing side-by-side tanks;

10 Figure 3 is a cross-sectional view of the ship and tanks of FIGS. 1 and 2 taken along lines 3-3 of FIG. 2;

Figure 4 is an enlarged side elevation view of a forward end of the tank of FIG. 1;

Figure 5 is an enlarged cross-sectional view of a wall of the tank of FIGS. 1-4 taken at detail 5 of FIG. 3 showing welds in each layer;

15 Figure 6 is an enlarged alternative cross-sectional view of Figure 3 wherein a top layer of the tank is connected to deck structure;

Figure 7 is an enlarged alternative cross-sectional view of Figure 3 showing an expansion space between each side of the tank and ship structure;

20 Figure 8 is an enlarged alternative cross-sectional view of Figure 3 showing an embodiment wherein the tank is supported by ship structure that is separate from deck structure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the Figures, shown is gas transport vessel **10**. Gas transport vessel **10** is made up of ship structure including a hull **20**. Hull **20** includes bottom shell portion **22**, starboard shell portion **24**, and port shell portion **26**. Upper deck **28** spans between starboard shell portion **24** and port shell portion **26**. Forward bulkhead **30** is located within hull **20** and rearward bulkhead **32** is located within hull **20**.

Hull **20** may be divided lengthwise by longitudinal bulkhead **34**. Longitudinal bulkhead **34** separates a port hold **36** and a starboard hold **38**. Port hold **36** and starboard hold **38** are located between forward bulkhead **30** and rearward bulkhead **32**. Starboard tank **40** is located in starboard hold **38**. Starboard tank **40** is constructed of multiple layers. In one embodiment, starboard tank **40** is constructed of six layers, i.e., outer layer **42**, second layer **44**, third layer **46**, fourth layer **48**, fifth layer **50**, sixth layer **52**, and liner layer **54**, (see, e.g., FIG. 5) wherein each of layers **42**, **44**, **46**, **48**, **50**, **52**, and **54** are made up of the following segments. Other numbers of layers may be provided, e.g., 3 to 10 layers.

Each of layers **42**, **44**, **46**, **48**, **50**, **52**, and **54** include body segment **60** (see, e.g., FIG. 4). Body segment **60** has a forward end **62** and a rearward end **64**. Body segment **60** is made up of upper semi-cylindrical portion **66** and lower semi-cylindrical portion **68**. Upper semi-cylindrical portion **66** and lower semi-cylindrical portion **68** are affixed to one another with a port body seam weld **70** and a starboard body seam weld **72**.

Forward end cap **74** is affixed to forward end **62** of body segment **60**. Forward end cap **74** is comprised of the following frusto-conical segments and a cap. Other constructions are also possible, such as a dome construction.

Referring now to Figure 4, each of layers **42**, **44**, **46**, **48**, **50**, **52**, **54** have a first frusto-conical segment **80** having an upper portion **82** and a lower portion **84** connected to one another via a first forward port seam weld (not visible in FIG. 4) and a first forward starboard

seam weld **88**. Upper portion **82** and lower portion **84** are preferably frusto-conical, single curvature layers to facilitate ease of construction. First forward frusto-conical segment has a forward edge **90** and a rearward edge **92**. Rearward edge **92** is affixed to forward end **62** of body segment **60** by a first forward circumferential weld **94**.

5 Each of layers **42, 44, 46, 48, 50, 52, 54** define a second forward frusto-conical segment **100** having an upper portion **102** and a lower portion **104** connected to one another via a second forward port seam weld **106** and a second forward starboard seam weld **108**. Upper portion **102** and lower portion **104** are preferably frusto-conical, single curvature layers to facilitate ease of construction. Second forward frusto-conical segment **100** has a
10 forward edge **110** and a rearward edge **112**. The rearward edge **112** of the second forward frusto-conical segment **100** is affixed to the forward edge **90** of the first frusto-conical segment **80** via a second forward circumferential weld **114**.

Each of layers **42, 44, 46, 48, 50, 52, 54** define a third forward frusto-conical segment **120** having an upper portion **122** and a lower portion **124** connected to one another via a third
15 forward port seam weld **126** and a third forward starboard seam weld **128**. Upper portion **122** and lower portion **124** are preferably frusto-conical, single curvature layers to facilitate ease of construction. Third forward frusto-conical segment **120** has a forward edge **130** and a rearward edge **132**. Rearward edge **132** of third forward frusto-conical segment **120** is affixed to forward edge **110** of second frusto-conical segment **100** via a third forward
20 circumferential weld **134**.

Each of layers **42, 44, 46, 48, 50, 52, 54** define a front plate **140** affixed to forward edge **130** of third forward frusto-conical segment **120** with a fourth circumferential weld **142**.

A rearward end cap (not visible in FIG. 4) is affixed to rearward end **64** of body **60**. The rearward end cap is preferably made up of multiple layers of frusto-conical segments and
25 an end cap similar to forward end cap **74**, described above.

A port tank **160** is located in port hold **36**. Port tank **160** preferably has a similar construction to that of starboard tank **40**, discussed above.

The ship **10** and the cargo containment system are sized in accordance with ABS rules. The containment system is designed under the Limit States provisions of the ABS

5 Guidelines for CNG Ships.

In one embodiment, the cargo tanks **40**, **160** are 20 meters in diameter with a wall thickness of 630 mm constructed in 6 layers of 100 mm and one inner layer of 30 mm. Other wall thicknesses are possible depending on the design conditions, tank size and cargo. Example wall thicknesses range from 20 mm to 200 mm and overall thickness range from
10 200 mm to 900 mm. In greater detail, although wall thicknesses will depend on the size and operating conditions of the tanks, contemplated wall thicknesses for each layer are in the range of 20 to 200 mm, more particularly 70 to 150 mm, and more particularly 100 to 120 mm. Overall thicknesses range from 200 to 900 mm, more particularly 400 to 700 mm, and more particularly 500 mm to 600 mm. Other thicknesses may be necessary depending on
15 design considerations.

Nesting multiple cylinders inside each other, each with a wall thickness of about, e.g., 100 mm (see detail A; FIG. 5), facilitates ease of fabrication of a cylinder having sufficient wall thickness to provide adequate provable resistance to crack growth.

The wall therefore consists of multiple layers, e.g., layers **42**, **44**, **46**, **48**, **50**, **52**, **54**,
20 such as 6 layers of 100 mm thick X80 steel with a liner that resists embrittlement such as a stainless-steel liner **54** that is 30 mm in thickness. The stainless-steel liner **54** is provided to prevent the X80 material from hydrogen embrittlement. Other possible liner materials that resist embrittlement are possible, including aluminum and plastic. Visible in Figure 5 are seam welds, e.g., seam weld **72** for each of layers **42**, **44**, **46**, **48**, **50**, **52**, and **54**, designated as
25 seam weld **72** and **72a-e** as shown in FIG. 5.

This nesting of cylinder layers is beneficial to the fracture mechanics problem as crack growth in a single cylinder becomes arrested since the stress at the crack tip diminishes. More importantly, the crack cannot jump the boundary to the adjacent layer due to lack of continuity.

5 With big tanks under such high pressure the energy stored is very large. Even though fatigue resistance can be demonstrated, the tanks of the invention ensure that, even if a crack developed, it could not progress beyond its critical length between inspections.

Some secondary advantages of the invention are that the deck stress in the ship **10** due to the design bending moment drops to about a third or so of what it would be in an equivalent sized tanker. This means that some steel weight reductions in the ship's structure may be possible. They have not been allowed for in the initial estimates of ship steel weights. Additionally, the longitudinal stress in the 20-meter pipe tanks **40, 160** (due to the design wave and still water moment) is miniscule, as is the shear stress.

Cargo Containment Design

15 The containment design is governed (primarily) by two limit states. That of service (SLS) and that of fatigue.

If the ship **10** were to have a complete cycle of load-unload every 5 days, then over 30 years this amounts to 2,200 cycles.

The American Bureau of Shipping (ABS) requires that a factor of 10 be applied when
20 assessing design life using S-N fatigue curves. Also, the curves used must be conservatively based on 3 standard deviations below the mean failure line, (as opposed to the more normal industry standard of 2).

For 250 bar the fatigue formula results in 24,000 cycles which is in excess of the 22,000 required.

25

Ship Principal particulars

The principal characteristics of example vessel **10** are as follows:

	LOA	340m
	Waterline	325m
5	Maximum Breadth	48m
	Depth to Main Deck	26m
	Loaded Draft	12.0m
	Lightship Draft	11.8m
	Loaded Displacement	160,000 tonnes
10	Freeboard	14.0m
	Cargo Weight	2,000 tonnes
	Cargo Volume	118,000 m ³
	Ship Steel	22,000 tonnes of EH36 steel
	Ship to Cargo volume ratio	2.9:1 (average tanker is 1.5:1)
15	GM	8.5 m
	Roll Period	11 seconds
	Hull Inertia	4300 m ⁴
	Hull Modulus	330 m ³
	Maximum Deck Stress	7 ksi (about 30% of allowable)
20	Example Containment Design	
	250 bar	
	Yield Stress:	80 ksi
	OD:	20,000 mm
	Wall Thickness:	630mm
25	Nominal hoop stress at 250 bar	56 ksi

Nominal safety factor with respect to yield	1.4
Length:	225m (201m+12m+12m)
Total pipe weight	133,000 tonnes
(127,000 tonnes of 80 ksi steel plus 6000 tonnes of stainless steel)	

5 **Example Calculation of Allowable Pressure**

The permissible SLS design pressure for safety class high, under the DNV Submarine Pipeline Systems code OS-F101 Clause D 400, is derived below. The operating pressure (MAOP) is then 95% of this value.

10 The formula for the permissible design pressure for the serviceability (yield) limit state is:

$$\text{Design Pressure} = 2 \times t_{\min} \div (\text{OD} - t_{\min}) \times \alpha_u \times f_y \times 2 \div 3^{0.5} \div \gamma_{sc} \div \gamma_m$$

Where:

- $t_{\min}$ = the minimum wall thickness of the pipe at any point,
- OD = the outside diameter
- 15 f_y = the minimum specified yield stress
- α_u = equals the material strength factor or 0.96
- γ_{sc} = equals the safety class safety factor. In this case for the highest class it is 1.308
- γ_m = equals the material safety factor.

20 Putting numerical values into the above formula yields:

250 bar

$$\begin{aligned} \text{Design Pressure} &= 2 \times 24.8 \div (787.4 - 24.8) \times 80,000 \times 0.96 \times 2 \div 1.732 \div 1.308 \div 1.15 \\ &= 3835 \text{ psi. (264 bar)} \end{aligned}$$

Multiplying by 0.95 gives an MAOP of 3642 psi. **(251 bar)**

25 **Example Fatigue Assessment**

ABS have indicated in their guidelines that a factor of 10 be used when assessing design life with the appropriate S-N curves, which are conservatively based on 3 standard

deviations below the mean failure line (as opposed to the more normal industry standard of 2).

The relationship between the number of cycles and the stress range can be written as:

$$\text{Log}(N) = \text{Log}(C) - c\delta - m \text{Log}(F_{sr})$$

5 Where:

N = the predicted number of cycles to failure under the stress range F_{sr}

C = a constant relating to the mean S-N curve for that weld.

m = the inverse slope of the mean S-N curve.

c = the number of standard deviations below the mean

10 δ = the standard deviation of Log(N)

Inserting numerical values into the equation yields the following:

250 bar Class C weld

$$\text{Log}_{10}(N) = 14.034 - 3 \times 0.204 - 3.5 \text{Log}(384) = 4.377$$

From which N equals $10^{4.377} = \mathbf{24,000 \text{ cycles}}$

15 In one embodiment, damage stability requirements are met primarily by the continuance inwards of some of the watertight bulkheads **30, 32** in the outer double hull side shell where they will make a watertight seal with the cylinders **40** and/or **160**.

In one embodiment, compartmentalization within the storage tanks **40, 160** is achieved by introducing divisions into the long cylinders if required.

20 In one embodiment, the nested tanks are constructed by first installing the outer lower circular section, e.g., **68** of layer **42** (see, e.g., FIG. 4), and welded to the super structure. Then the rest of the lower semicircular portions of layers **44, 46, 48, 50, 52, and 54** will be seated under gravity. Preferably, there are no weld connections between the shells. Then the top inner semicircular section, e.g., **66**, will be lowered on to the bottom inner section, e.g.,
25 **44, 46, 48, 50, 52, and 54**, and the inner seam weld, e.g., **70, 72**, will be completed from both

sides. This then continues with single sided welding until the outer top section **66** is seam welded onto its counterpart via seam welds **70, 72**, see FIG. 5, Detail A above.

The length of each section will depend on the crane capacity of the yard. A 50 meter section would weigh about 1400 tonnes. The very high D/t ratios of the 100 mm thick half cylinders make them very easily alignable for seam welding by various combinations of kentledge, hydraulic and temperature means. The end caps **74, 144** are specifically designed with single curvature in order to assist forming and fit up.

Moss tanks for LNG require equatorial ring support. This is because their internal design pressure is so low that the resulting shell cannot self-support from beneath. However, in one embodiment, Applicant's tanks **40, 160** are e.g., 250 bar cylinders that have a working pressure some 500 or more times that of a Moss tank and as such are easy to support from beneath. This support also acts as the shear transfer mechanism to transfer bending moment to ship structure, such as the ship's deck **28** and bottom shell. Moss tanks are not typically integrated with the ship **10**. Applicant's tanks **40, 160** are integrated completely and are the stiffest and strongest part of part of the ships structure. By welding the top and bottom of tank **40, 160** to ship structure, such as deck structure, tank **40, 160** becomes a major structural element of the ship, thereby adding to the strength of the ship. Perhaps the best analogy is that of a second world war submarine which has its upper deck attached as an appurtenance rather than a load carrying member. The main support for tanks **40, 160** comes from both horizontal and longitudinal girders. The transverse support will be from the transverse girders and the watertight bulkheads **30, 32** described above. The longitudinal girders (top and bottom) will also be used as shear transfer connections to the deck **28** and tank shell.

As shown in Figure 6, outer layer **42** of tank **40** may be connected to deck **28**, e.g., by welding to support **39**. Support **39** is shown in Figures 6 and 7 as being part of ship structure of deck **28**. However, support **39** may be provided for supporting tank **40** as ship structure

that is separate from deck **28** (see, e.g., FIG. 8). Sagging of layers **42, 44, 46, 48, 50, 52** and **54** is prevented by welding outermost layer **42** to a support **39** or to girders of top deck **28** of ship **10**. The connection to deck **28** supports outermost layer **42** and prevents it from sagging. Since top layer **42** does not sag, inner layers **44, 46, 48, 50, 52** and **54** cannot deform and sag
 5 since they are nested within outer layer **42** whose geometry is constrained by attachment to top deck **28**.

As shown in Figure 7, expansion space **43** and **45** may be provided between tank **60** and structural shell portion **24** of hull **20** and between tank **40** and longitudinal bulkhead **34**, respectively. Expansion gaps or spaces **43** and **45** prevent tank from **60** damaging ship hull
 10 **20** as tank **40** expands during pressurization.

Preferably, the nested tanks are not connected to each other in any way. They are tubes within tubes. If there were no ends and they were perfectly constructed then they would slide out. Imagine the nested tube spanning as a beam from end to end under self-weight giving a simple bending moment. The stress and deflections are based on the inertia of the
 15 tubes. If the tubes are in close contact and there are no gaps the overall inertia of the tubes is the exact same as if they were solid. It is completely different than having multiple layers of plate on top of one another. The inertia of the nested tubes is calculated as follows:

$$\text{Inertia} = \pi/64 (D_1^4 - D_2^4 + D_2^4 - D_3^4 + D_3^4 - \dots) = \pi/64 (204 - 18.744) = 1800 \text{ m}^4$$

With two tanks this is 3600 m^4 . Total hull and cylinder inertia acting together is
 20 4300 m^4 so about 80% of the ship's stiffness comes from the cargo tanks **40, 160**.

* * * *

Thus, the present invention is well adapted to carry out the objectives and attain the ends and advantages mentioned above as well as those inherent therein. While presently preferred embodiments have been described for purposes of this disclosure, numerous

changes and modifications will be apparent to those of ordinary skill in the art. Such changes and modifications are encompassed within the spirit of this invention as defined by the claims.

It is to be understood that the terms "including", "comprising", "consisting" and
5 grammatical variants thereof do not preclude the addition of one or more components, features, steps, or integers or groups thereof and that the terms are to be construed as specifying components, features, steps or integers.

If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

10 It is to be understood that where the claims or specification refer to "a" or "an" element, such reference is not be construed that there is only one of that element.

It is to be understood that where the specification states that a component, feature, structure, or characteristic "may", "might", "can" or "could" be included, that particular component, feature, structure, or characteristic is not required to be included.

15 Methods of the present invention may be implemented by performing or completing manually, automatically, or a combination thereof, selected steps or tasks.

The term "method" may refer to manners, means, techniques and procedures for accomplishing a given task including, but not limited to, those manners, means, techniques and procedures either known to, or readily developed from known manners, means,
20 techniques and procedures by practitioners of the art to which the invention belongs.

The term "at least" followed by a number is used herein to denote the start of a range beginning with that number (which may be a range having an upper limit or no upper limit, depending on the variable being defined). For example, "at least 1" means 1 or more than 1. The term "at most" followed by a number is used herein to denote the end of a range ending
25 with that number (which may be a range having 1 or 0 as its lower limit, or a range having no

lower limit, depending upon the variable being defined). For example, “at most 4” means 4 or less than 4, and “at most 40%” means 40% or less than 40%.

When, in this document, a range is given as “(a first number) to (a second number)” or “(a first number) – (a second number)”, this means a range whose lower limit is the first
5 number and whose upper limit is the second number. For example, 25 to 100 should be interpreted to mean a range whose lower limit is 25 and whose upper limit is 100. Additionally, it should be noted that where a range is given, every possible subrange or interval within that range is also specifically intended unless the context indicates to the contrary. For example, if the specification indicates a range of 25 to 100 such range is also
10 intended to include subranges such as 26 -100, 27-100, etc., 25-99, 25-98, etc., as well as any other possible combination of lower and upper values within the stated range, e.g., 33-47, 60-97, 41-45, 28-96, etc. Note that integer range values have been used in this paragraph for purposes of illustration only and decimal and fractional values (e.g., 46.7 – 91.3) should also be understood to be intended as possible subrange endpoints unless specifically excluded.

15 It should be noted that where reference is made herein to a method comprising two or more defined steps, the defined steps can be carried out in any order or simultaneously (except where context excludes that possibility), and the method can also include one or more other steps which are carried out before any of the defined steps, between two of the defined steps, or after all of the defined steps (except where context excludes that possibility).

20 Further, it should be noted that terms of approximation (e.g., “about”, “substantially”, “approximately”, etc.) are to be interpreted according to their ordinary and customary meanings as used in the associated art unless indicated otherwise herein. Absent a specific definition within this disclosure, and absent ordinary and customary usage in the associated art, such terms should be interpreted to be plus or minus 10% of the base value.

Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned above as well as those inherent therein. While the inventive device has been described and illustrated herein by reference to certain preferred embodiments in relation to the drawings attached thereto, various changes and further modifications, apart
5 from those shown or suggested herein, may be made therein by those of ordinary skill in the art, without departing from the spirit of the inventive concept the scope of which is to be determined by the following claims.

CLAIMS

What is claimed is:

1. A fluid transport vessel comprising :
a hull;
5 a tank longitudinally received in said hull, said tank having a plurality of layers, said plurality of layers comprising an outside layer;
ship structure above said tank;
wherein said outside layer of said tank is supported by said ship structure.
2. The fluid transport vessel according to claim 1 wherein:
10 said ship structure supports a deck.
3. The fluid transport vessel according to claim 1 further comprising:
a forward bulkhead in said hull;
a rearward bulkhead in said hull;
wherein said tank is between said forward bulkhead and said rearward
15 bulkhead.
4. The fluid transport vessel according to claim 1 further comprising:
a longitudinal bulkhead in said hull, said longitudinal bulkhead separating said
hull into a port hold and a starboard hold;
a second tank in one of said port hold and said starboard hold;
20 wherein said tank is in one of said port hold and said starboard hold not occupied by said second tank.

5. The fluid transport vessel according to claim 1 wherein:
said plurality of layers comprises a number of layers between 3 layers and 10 layers, inclusive.
6. The fluid transport vessel according to claim 1 wherein:
5 said plurality of layers further comprises an inside layer; and
said inside layer is comprised of a material that resists embrittlement.
7. The fluid transport vessel according to claim 1 wherein:
said plurality of layers comprises an inside layer; and
said inside layer is comprised of a material that resists corrosion.
- 10 8. The fluid transport vessel according to claim 1 wherein:
said plurality of layers further comprises an inner layer and intermediate layers between said inner layer and said outer layer, said intermediate layers for providing additional strength to said tank.
9. The fluid transport vessel according to claim 1 wherein:
15 each layer of said plurality of layers has a forward end cap and a rearward end cap;
wherein said forward end cap and said rearward end cap of each of said layers are constructed of multiple frusto-conical sections.
10. The fluid transport vessel according to claim 9 wherein:
20 said frusto-conical sections define a single curvature.

11. The fluid transport vessel according to claim 1 wherein:
- at least one layer of said plurality of layers has a body segment having a forward end and a rearward end, an upper semi-cylindrical segment and a lower semi-cylindrical segment, said upper semi-cylindrical segment and said lower semi-cylindrical segment affixed to one another with a port body seam weld and a starboard body seam weld;
- a front end cap adjacent said forward end of said body segment;
- a rear end cap adjacent said rearward end of said body segment.
12. The fluid transport vessel according to claim 1 wherein:
- said outside layer of said tank has a top, a bottom, a port side and a starboard side;
- said top of said tank contacting ship structure;
- said bottom of said tank contacting ship structure;
- wherein a space is provided between said port side and ship structure and between said starboard side and ship structure for accommodating expansion of said tank.
13. The fluid transport vessel according to claim 1 wherein:
- each of said plurality of layers of said tank are unconnected to adjacent layers of said tank.
14. A fluid transport vessel comprising :
- a hull;
- a tank longitudinally received in said hull, said tank having a plurality of layers, said plurality of layers comprising an outside layer;

wherein each layer of said plurality of layers said tank has end caps constructed of multiple frusto-conical segments.

15. The fluid transport vessel according to claim 14 wherein:
the vessel includes structure above said tank; and
5 said outside layer of said tank is supported by said structure.
16. The fluid transport vessel according to claim 15 wherein:
said structure supports a deck.
17. The fluid transport vessel according to claim 14 further comprising:
a forward bulkhead in said hull;
10 a rearward bulkhead in said hull;
wherein said tank is between said forward bulkhead and said rearward bulkhead.
18. The fluid transport vessel according to claim 14 further comprising:
a longitudinal bulkhead in said hull, said longitudinal bulkhead separating said
15 hull into a port hold and a starboard hold;
a second tank in one of said port hold and said starboard hold;
wherein said tank is in one of said port hold and said starboard hold not occupied by said second tank.
19. The fluid transport vessel according to claim 14 wherein:
20 said plurality of layers comprises a number of layers between 3 layers and 10 layers, inclusive.

20. The fluid transport vessel according to claim 14 wherein:
said plurality of layers further comprise an inside layer; and
said inside layer is comprised of a material that resists embrittlement.
21. The fluid transport vessel according to claim 14 wherein:
5 said plurality of layers further comprise an inside layer; and
said inside layer is comprised of a material that resists corrosion.
22. The fluid transport vessel according to claim 14 wherein:
said plurality of layers further comprises an inner layer and intermediate layers
between said inner layer and said outer layer, said intermediate layers for providing
10 additional strength to said tank.
23. The fluid transport vessel according to claim 14 wherein:
said frusto-conical segments define a single curvature.
24. The fluid transport vessel according to claim 14 wherein:
at least one layer of said plurality of layers has a body segment having a
15 forward end and a rearward end, an upper semi-cylindrical segment and a lower semi-
cylindrical segment, said upper semi-cylindrical segment and said lower semi-
cylindrical segment affixed to one another with a port body seam weld and a starboard
body seam weld;
a front end cap adjacent said forward end of said body segment;
20 a rear end cap adjacent said rearward end of said body segment.

25. The fluid transport vessel according to claim 14 wherein:
- said outside layer of said tank has a top, a bottom, a port side and a starboard side;
- said top of said outside layer contacting ship structure;
- 5 said bottom of said outside layer contacting ship structure;
- wherein a space is provided between said port side and ship structure and between said starboard side and ship structure for accommodating expansion of said tank.
26. The fluid transport vessel according to claim 14 wherein:
- 10 each of said plurality of layers of said tank are unconnected to adjacent layers of said tank.
27. A method of constructing a multi-layer tank within a hull of a ship comprising the steps of:
- installing a semi-cylindrical outer lower section in the hull and affixing said
- 15 outer lower section to said hull;
- installing one or more semi-cylindrical lower sections within said outer lower section, said semi-cylindrical lower sections comprising an inside lower section;
- installing a semi-cylindrical inside upper section on said inside lower section and welding said inside upper section to said inside lower section on both sides for
- 20 forming an inside cylinder;
- installing one or more semi-cylindrical upper sections for mating with counterpart ones of said semi-cylindrical lower sections and welding each mated pair on both sides for forming a plurality of nested cylinders;

installing end caps on each of said plurality of nested cylinders for forming a plurality of nested tanks.

28. A method of strengthening a vessel for transporting fluid, said method comprising steps of:

5 locating a multi-layer tank longitudinal within a hull of a ship, said multi-layer tank having an outside layer having a top and a bottom;

 securing said bottom of said outside layer to ship structure below said multi-layer tank;

 securing said top of said outside layer to ship structure above said multi-layer
10 tank;

 wherein said securing steps integrate said multi-layer tank with said ship structure for allowing said multi-layer tank to become a structural element of said vessel, thereby adding strength to said vessel.

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