Abstract: A pressure vessel (10) for naval transportation of CNG comprises a vessel body adapted to receive and contain CNG, and an external layer (202) of a cushioning and thermally insulating material for insulating thermally at least a portion of the CNG. The thermally insulating material (202) is distinct from the vessel body. For example, it is a foam material. A rigid or semi-rigid skin or skirt (204) of a structural material can also be provided in contact with at least a portion of the cushioning and thermally insulating material (202), on the outer side thereof, to enable the pressure vessel (10) to be supported in a desired position on ships (301) or the like.

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PRESSURE VESSELS AND APPARATUS FOR SUPPORTING THEM ONBOARD SHIPS

The present invention relates to pressure vessels and to ship-based support apparatus therefor, such as an apparatus comprising structural elements to hold the pressure vessels in a desired configuration or position onboard a boat, a ship or another form of carrier vehicle, especially waterborne carrier vessels. In particular, the present invention relates to pressure vessels and to support apparatus therefor for naval transportation of compressed natural gas (CNG).

Natural gas is a valuable natural resource often found in natural underwater reservoirs. Natural gas can be extracted from such reservoirs, and then transported to land on ships, boats or the like. The present invention is directed towards such transportation where the natural gas takes the form of CNG.

Land based applications are also envisioned, e.g. extraction and transportation from natural underground reservoirs.

CNG is a form for the natural gas that allows commercially viable quantities of natural gas to be contained and stored within the limited space available onboard ships or boats, and land based transportation trucks. Various different forms of pressure vessel (i.e. pressure vessels made of different materials and having different sizes, shapes and/or accessory features) can be used to transport this CNG. On water, larger pressure vessels, and more of them, are arrangeable together since ships can be significantly larger than road-going vehicles and trains. Nevertheless, the present invention is applicable to all these forms of transportation.

CNG pressure vessels are generally designed to operate up to a certain maximum internal safe working pressure. If these internal maximum pressures are exceeded, safety can be compromised. Further, even within the limits of such maximum internal safe working pressures, pressure fluctuations inside the vessels are undesirable because they can generate cyclic stresses in the vessels' walls and that can lead to fatigue-type damage or failure.
When transported on a vehicle, and particularly boats or ships, CNG pressure vessels will experience external forces thereon from the supporting means used to support, hold or fix the pressure vessels into position on the vehicle, such as on a ship’s decks, within the ship's storage compartments or within the ship's hull. Such support forces contribute, together with the internal CNG pressure-induced stresses, to the overall amounts of stress generated in a given vessel's walls. This is especially the case for large, tall and relatively heavy pressure vessels, since such pressure vessels need to be secured very firmly.

The external supporting forces acting on ship-based CNG pressure vessels, and therefore the resulting total stresses in the walls of the pressure vessels, can further be exacerbated by the oscillations of the ships on the water (pitching, rolling and yawing), e.g. as a result of waves, and in extreme circumstances, e.g. due to storm conditions, these additional forces can be very significant. For example, heavy rolling of a boat or ship can greatly increase the spot-loading caused by the supports, e.g. as transmitted by a supporting bracket or cage, to a CNG pressure vessel being transported on the boat or ship.

The maximum external forces exerted by the supports on CNG pressure vessels depend on the configuration of the supports, and also on the configuration of the pressure vessels within the ship, and also upon the angles to which the ship can pitch, roll or yaw. Therefore, unless designed correctly, under extreme weather or sea conditions, pressure vessels can experience external loadings, or bending moments, that could result in a flexural failure or buckling due to stress concentrations of one or more of the pressure vessels on the ship. The same can also apply on trains, planes and road vehicles.

It is an object of the present invention to mitigate the above-mentioned risks.

According to an aspect of the present invention there is provided a device comprising a pressure vessel for transportation of CNG, the vessel comprising a vessel body adapted to receive and contain CNG, and the device further comprising a layer of a cushioning and thermally insulating material, external of the vessel, for thermally insulating at least a portion of the vessel, wherein the cushioning and thermally insulating material is distinct from the vessel body so that the cushioning and thermally
insulating material can work both as a thermal insulator and as a cushioning element for supporting and protecting the pressure vessel.

Preferably the vessel is for naval transportation of CNG, whereby the cushioning and thermally insulating material can work both as a thermal insulator and as a cushioning element for supporting and protecting the pressure vessel onboard of a ship.

Thermo-insulating devices and materials are particularly suitable for CNG pressure vessels when the natural gas transportation foresees chilled cargo (chilling decreases the transportation pressure for a given quantity of natural gas, or maintains a given pressure for an increased quantity of natural gas.

The cushioning and thermally insulating material can comprise one or more material selected from foams, polymers and elastomers such as rubbers. A layer of metallic foam may also be used, which layer may be in addition to, or part of, the cushioning and thermally insulating material, or it may have resilience, whereby it forms the cushioning and thermally insulating material.

Preferably the cushioning and thermally insulating material is generally homogeneous and/or isotropic. Preferably it has a high free/void volume. Such materials will generally be particularly effective at cushioning and insulating the vessel, or the part thereof.

Preferably, a rigid or semi-rigid skin or skirt of structural material is provided in contact with at least a portion of the cushioning and thermally insulating material, e.g. on an outer side thereof, to work as a structural interface to attach or hold the vessel in cooperation with a holding apparatus on the vehicle.

The skin or skirt can also serve to protect the cushioning and thermally insulating material.

The skin or skirt may properly transfer and distribute loads through the insulating structure.
CNG pressure vessels usually have a round longitudinal cross section. Often they are in the shape of a cylinder or tube with end caps. The end caps often have a dome-shape.

The thermally insulating material can be provided in such a way that it fully surrounds the vessel body at least at one plane of the vessel body (i.e. for example a cross-sectional plane of the vessel body). The thermally insulating material may extend along a perimeter or length of the pressure vessel, or all around the pressure vessel, to wrap at least a space or volume of the pressure vessel. The thermally insulating material can be provided in the shape of a ring or tube of material extending all around the main cylindrical body of the pressure vessel, which can be entirely or partially covered by that ring or tube. The main part of the pressure vessel can thus be insulated.

Using the insulating material allows the CNG stored inside the pressure vessel to be well insulated in that the CNG will be insulated against temperature variations coming from pretty much any angle, e.g. from direct sunlight or from icy cold winds.

Preferably, the skin or skirt of structural material will extend over, or cover up fully, the thermally insulating material, so that the pressure vessel can be supported in cooperation with the skin and the thermally insulating material at any chosen location(s) over the area covered by the skin and the thermally insulating material. Further the full covering makes the insulating material better protected by the skin.

The pressure vessel can be equipped with supporting means for connecting the pressure vessel to hull, chassis or framework of a vehicle, such as a ship or boat, such that the pressure vessel can be supported in a desired position on that vehicle, e.g. board, or in the hull of, a ship or boat.

The supporting means can be attached to the skin or skirt of structural material, which offers many potential attachment locations - direct contact between the thermally insulating material and the supporting means could in theory be damaging for the thermally insulating material.

To better support the pressure vessel, the supporting means can comprise a ring-shaped holder or bracket. Two ring shaped holders or brackets around the thermally
insulating material, in spaced apart configuration, or a cage comprising several spaced apart rings, are also possible and advantageous, especially if the pressure vessels are supported vertically. These rings may be located over the skin(s) or skirt(s), or may themselves be the skin(s) or skirt(s).

According to another aspect of the present invention, there is provided an apparatus for supporting CNG pressure vessels on a vehicle, the apparatus comprising:

- means for fixing the apparatus to the vehicle; and
- means for supporting at least one CNG pressure vessel in a desired position on the vehicle;

wherein the apparatus comprises a layer of a thermally insulating material for thermally insulating at least a portion of the at least one pressure vessel, said layer being also configured to form a cushion in the apparatus between the at least one pressure vessel and the supporting means when the at least one pressure vessel is supported by the supporting means in the apparatus.

The apparatus may be permanently fixed to the vehicle.

The vehicle may be a ship or boat.

The apparatus may be configured for supporting the pressure vessel substantially vertically. Vertically supported pressure vessels usually are more protected against support-damage caused by rolling, pitching or yawing of the vehicle.

Suitably, the layer of thermally insulating material can be one or more of foam, polymer or elastomer such as rubber. These materials frequently are good thermal insulators and frequently offer good structural cushioning or damping properties.

A rigid or semi-rigid skin or skirt of structural material can be interposed between the pressure vessel supporting means and at least a portion of the thermally insulating material. An interface is thus able to be provided between the supporting means and the thermally insulating material. The skin protects the thermally insulating material against fractures and ruptures at the locations where forces are transmitted from the supporting means.
Preferably, the thermally insulating material has extends fully around the vessel at least on one cross sectional plane thereof.

The thermally insulating material may have a generally tubular shape. With the thermally insulating material having a generally tubular shape, the pressure vessel can be conveniently supported thereby, especially if the pressure vessel has an external size and shape to match the internal size and shape of the tubular shape - e.g. typically a cylindrical body.

The skin or skirt of structural material can be provided to extend over the thermally insulating material, and can fully cover the thermally insulating material, thereby providing a degree of structural protection for the thermally insulating material.

The pressure vessel supporting means may comprise one or more ring-shaped supporting member. Such ring members, are particularly versatile, especially with cylindrical pressure vessels.

The pressure vessel supporting means may comprise a first supporting member, and a further supporting member, either or both of which are ring-shaped.

Where more than one supporting member is provided, they will typically be spaced apart one from the other, so that the pressure vessel will be supported by the two or more spaced-apart supporting members in cooperation. This provides additional stability to the pressure vessel.

Embodiments of the present invention will now be described in greater detail, purely by way of example, in connection with the following drawings, in which:

Fig 1 is a schematic cross sectional representation of an embodiment of a CNG pressure vessel in accordance with the present invention arranged for being supported vertically onboard a CNG pressure vessel carrier ship;

Figure 2 is a schematic side view of a CNG pressure vessel according to a second embodiment of the present invention, in partial section, and supported vertically
onboard a CNG pressure vessel carrier ship. Figure 2 also comprises a magnified cross-sectional detail of the CNG pressure vessel; and

Figure 3, which also comprises a magnified cross-sectional detail of its CNG pressure vessel, is a schematic cross-sectional representation of a CNG pressure vessel again supported vertically on a CNG pressure vessel carrier ship, with and without a cushioning sleeve of a thermally insulating material.

Figure 1 shows a "type 3" multi-layer CNG pressure vessel 10 with an external jacket, sleeve or layer 202 (which is schematically represented by the crossed-dot region in Figure 1) of a thermally insulating material, which in this embodiment is polyurethane foam. A "type 3" vessel denotes a vessel that has an external structural layer made of a composite, fibre reinforced, material and an inner metallic liner. The external composite material provides the structural strength of the vessel, while the inner liner provides an impermeable layer for containment of the CNG.

A typical thermal property of polyurethane foam would be a thermal conductivity in the range of 0.02 to 0.04 W/mK at near-ambient temperature.

The thermally insulating sleeve covers the pressure vessel's central cylindrical part, which extends between two end caps - a first end cap 12 and a second end cap 11. Both end caps 11, 12 are provided with, in this embodiment, their respective apertures, e.g. for charging or discharging CNG, or for cleaning and inspection of the inside thereof.

The pressure vessel 10 of Figure 1 is supported vertically on a ship's hull or deck 301, which means that the first end cap 12 is positioned at a lower end 102 of the pressure vessel, and the second end cap 11 is positioned at an upper end 101 of the pressure vessel.

Upper aperture 6 is designed to be used as an inspection port, or manhole, so that an inspector can access the inner volume of the pressure vessel 10. In this embodiment, the aperture 6 is an 18 inch (45cm) wide manhole for access into the pressure vessel from above. Other embodiments may have a 24 inch (60cm) manhole. The manhole 6 is preferably provided according to ASME (American Society of Mechanical Engineers)
standards. The manhole 6 has a sealed or sealable cover or other closing means, allowing sealed closing of the opening, and allowing internal inspection when the vessel 10 is not in use, such as by a person climbing into the vessel through the opening/manhole.

In the present embodiment, the thermally insulating material 202 does not extend to cover the manhole 6. However, if required, the thermally insulating layer can extend to cover the manhole, so long as access to the vessel is still possible, e.g. by providing an openable or removable layer of thermally insulating material over the manhole 6. Such an arrangement might encompass the concept of an insulated manhole cover.

The thermally insulating material 202 is there to provide a "cushion" in addition to providing insulative properties in respect of heat transfers (either heat loss or heat gain). Suitable materials can be mechanically damping materials, for example materials suitable for absorbing shocks or vibrations that may be transmitted between the pressure vessel and structural elements (which are schematically represented by numeral 300 in Figure 1), such as those used for supporting the vessel in place on the deck or hull 301.

In Figure 1, the ship is schematically shown just as an anchor point for the pressure vessel 10.

It will be recognised that popular materials with suitable cushioning properties would include foams, polymers and elastomers such as rubbers, plus composite materials involving combinations or multiples of these basic classes of material.

The cushioning layer 202 will generally not be sufficiently robust on its own to support the pressure vessel in its position on the boat during transportation due to the potential for rough seas to greatly shake the pressure vessels. The structural supporting elements 300 are provided to hold the pressure vessels relative to the hull or deck, and they can be beams, rods, bars, cages, grids and combinations thereof, or any other suitable heavy duty construction, so as to provide a structure that can restrain the pressure vessels, but typically, the cushioning and insulating material is insufficiently structural to be a suitable structure onto which to secure the supporting elements. A structural skin is therefore provided over the insulating material, as discussed below.
As it can be seen in Figure 1, the tube of cushioning and thermally insulating material is provided in that embodiment only around the central, cylindrical part of the vessel 10. In alternative embodiments, such a material can be provided as a "jacket" to surround the pressure vessel in its entirety, or so as to wrap partially over the end caps, e.g. to still leave a space for loading and offloading of CNG. In further embodiments, some of which will be described below, two or a plurality of thermally insulating sleeves may be provided around the vessel, along its length, either abutting one another, or spaced apart along the length of the pressure vessel. It is not necessary that the whole surface of the cylindrical or main part of the pressure vessel be covered by the cushioning and thermally insulating material, although leaving gaps does reduce the degree of thermal insulation provided for the pressure vessel. Nevertheless, it is not necessary always to offer the maximum possible degree of insulation for the pressure vessel.

The lower aperture 7 is the inlet and outlet port for filling and emptying the vessel. It can be a 12 inch (30cm) opening, which is one highly suitable size for connecting to CNG transfer pipework. This aperture too will usually be provided with closing and sealing means, such as flanges or the like, to isolate the CNG from the outer environment.

The thermally insulating material 202 can optionally cover the opening 7 and the respective pressure vessel end cap 12, so long as the operations of loading and offloading are not impaired. This can be achieved for example with an openable or removable jacket in correspondence with the aperture 7.

In Figure 1, an impermeable metallic liner 1 is provided inside the pressure vessel, which forms the inner wall of the pressure vessel. However, alternative CNG impermeable liner materials can be used, such as HDPE or other resins (these materials are used as liners to form "type 4" pressure vessels).

A first fiber layer 2 about the liner 1, according to the illustrated embodiment, is a fiber-reinforced polymer based on carbon/graphite. However, alternative reinforcement for the composite can be used such as glass, aramid or metal fibers.
It substantially fully wraps the vessel (including most of the vessel ends) and it is arranged to be providing structural contribution during service.

This layer provides a degree of thermal insulation to stored CNG, but the thermal insulation gained by the external layer 202 is in addition to that insulation, and can greatly improve the insulative properties of the arrangement.

A second fiber layer 3, according to the illustrated embodiment, has also an insulating and protective function. In use, it can be in direct contact with the external environment, for example in the region of the end caps 11, 12 in Figure 1 (the cylindrical part of the pressure vessel is instead shielded by additional layers 202, 204). The second external fiber layer 3 can be a polymer or a fiber-reinforced polymer, e.g. based on glass fibers, due to its inert behaviour in aggressive and marine environments, and due to its insulating properties in terms of low thermal conductivity. E-glass or S-glass fiber is one preferred fiber for use for the fiber component of the second layer 3.

The pressure vessel 10 of Figure 1 can be manufactured independently from the outer components 202, 204, which can be added or installed on the pressure vessel at a later stage.

Pressure vessels of different types can be retrofitted with a thermally insulating sleeve 202 so as to be in accordance with the present invention.

A skin or skirt of structural material 204 (for example a thin tube of steel) is also provided in the embodiment of Figure 1, externally of the thermally insulating jacket 202. In this case, the skirt 204 is cylindrical and its internal diameter is generally the same as the external diameter of the thermally insulating jacket. The internal diameter of the skirt 204, however, can be conveniently slightly smaller than the outer diameter of the thermally insulating sleeve 202 prior to the skirt's application thereto, so that the thermally insulating material 202 is slightly compressed inside the outer skirt 204 after the application thereof thereto. This creates an interference fit.

Due to this interference fit, the skirt 204 cannot be disengaged or disassembled from the thermally insulating sleeve, without difficulty, which is desirable.
The purpose of the skin or skirt 204 is that of providing a mechanical interface for attachment to external supporting means 300, and also to offer protection for the inner layer. To this purpose, the skin or skirt 204 can be made from a rigid or semi-rigid material, such as a metal sheet or metal membrane. The rigidity of it can be determined according to its thickness, or its structural form, or both. For example, ribs can stiffen it.

The attachment between the skin 204 and said supporting means 300 can be performed in different ways, as it is known generally in the art of construction, for example by welding, bolting, riveting etc...

The method of attachment between the skin 204 and the supporting means 300, which are connected to the ship 301, is not described in additional detail here as that detail is not an essential feature of the present invention.

Importantly, the skin or skirt 204 also serves to protect the thermally insulating materials against ruptures, cracks or cuts which could occur if the thermally insulating material came into direct contact with the supporting means 300.

The skin or skirt 204 and the insulating layer 202 form together a protective shell for the pressure vessel. It is this protective structure which is connected to the ship via the supporting means 300. The pressure vessel is therefore itself not directly connected to the supporting means 300 by means of conventional structural elements. The pressure vessel is instead connected to the ship 301 via its outer shell, which comprises the skirt 204 and the cushioning thermally insulating layer 202 which supports directly the pressure vessel. The vessel is therefore protected from direct restraint forces, and thus has fewer point loadings thereon during transit.

The cushioning and thermally insulating material 202 ensures that the CNG stored inside the vessel is shielded, at least to a degree, against temperature fluctuations of the external environment, and it ensures that at the same time the vessel is protected against its own support forces, i.e. the forces exerted on the vessel 10 by the external supports 301. This means that the pressure vessel's walls will be protected, at least to a certain degree, both against possible fluctuating stresses due to any temperature-induced internal pressure variations in the CNG, and against the stresses caused by
the action of the supporting forces applied on the vessel 10 by the external supporting means 301.

The presence of the cushion 202 means that the supporting forces are smoothly distributed over larger areas (see Figure 3). With the present invention, CNG pressure vessels can, therefore, advantageously be held in position on their carrier ships. Bad weather or rough sea conditions, as it is known, can increase the magnitude of the supporting forces acting on the CNG pressure vessels, at least during intervals of time. The cushioning layer 202 can therefore protect the CNG pressure vessels when these peaks occur.

In addition, because the cushion is also thermally insulating, the protective function of the intermediate structure 202, 204 interposed between the pressure vessel and its supporting means 300 extends in respect of the action of the internal pressure forces due to the CNG.

In some embodiments, the intermediate structure 202, 204 can be provided on the ships as part of the supporting means for holding the pressure vessels. In these embodiments, therefore, such intermediate structures, or parts thereof, are provided independently from the provision of the pressure vessels themselves, and the vehicle with its pressure vessel supporting support structures can be assembles separate from the pressure vessels. Then the pressure vessels can be inserted at a later stage in the intermediate protective structures already provided in the vehicle, or they can be removed and replaced as necessary - the pressure vessels may have a limited cyclic life, e.g. 1,000 to 4,000 cycles of loading and unloading prior to there being a need either to extend their life through further testing and certification or to decommission the ship or other mean of transport, or to decommission each aged pressure vessel.

The pressure vessels may want to be earthed to the ship's hull, or the vehicle's chassis, or the intermediate structure's skirt, especially if the insulating material is not electrically conductive. Likewise the skirt may want to be so earthed. This ensures no static electricity build-up, e.g. caused by rubbing between the vessel and the insulating material, whereby sparks will not occur - important for CNG transportation due to the flammable nature of the product.
Figure 2 shows a pressure vessel 10 comprising an internal metallic liner 100 as a first layer 100 capable of hydraulic or fluidic containment of CNG, and an external composite layer 200. This pressure vessel too can therefore be categorised in the "type 3" family. It too is vertically supported on a ship 501 (schematically represented in Figure 2 as an anchor point) by supporting means 500, which can be of any conventional form, as per the previous embodiment, such as metal brackets and the like, the details of which are not specified in detail herein.

In this embodiment, the metallic liner, as the first layer 100, is not required to be provided in such a form to provide a structural function during CNG transportation, in particular during sea or marine transportation, or during loading and offloading phases. However, it is preferred that it should be at least corrosion-proof. Further it is preferred for it to be capable of carrying non-treated or unprocessed gases, e.g. by being impervious to such gases. Hence the preferred material is a stainless steel, or some other metallic alloy.

The stainless steel is preferably an austenitic stainless steel such as AISI 304, 314, 316 or 316L (with low carbon percentages). Where some other metallic alloy is used, it is preferably a Nickel-based alloy or an Aluminium-based alloy, such as one that has corrosion resistance.

The metallic liner forming the first layer 100 preferably only needs to be strong enough to withstand stresses arising from manufacturing processes of the vessel, so as not to collapse on itself at that time, such as by being strong enough to withstand the stresses imposed thereon during fiber winding processes. This is sufficient strength because the structural support during pressurized transportation of CNG will be provided instead by the external composite layer 200.

The external composite layer 200, which uses at least one fiber layer, will be a fiber-reinforced polymer. The composite layer 200 can be based on glass, or on carbon/graphite, or on aramid fibers, or on combinations thereof, for example. The external composite layer is used as a reinforcement which fully wraps the outside of the first layer 100, including the vessel's ends 11, 12, and it provides the structural strength for the vessel during service.
In the case of glass fibers, is it preferred but not limited to the use of an E-glass or S-glass fiber.

Preferably, the glass fiber has a suggested tensile strength of 1,500 MPa or higher and/or a suggested Young Modulus of 70 GPa or higher.

In the case of carbon fibers, is it preferred but not limited to the use of a carbon yarn, preferably with a tensile strength of 3,200 MPa or higher and/or a Young Modulus of 230 GPa or higher.

Preferably there are 12,000, 24,000 or 48,000 filaments per yarn.

The composite matrix is preferred to be a polymeric resin, thermosetting or thermoplastic. If a thermosetting resin, it may be an epoxy-based resin.

The manufacturing of the external composite layer 200 over the said metallic liner (the first layer 100) preferably involves a winding technology. This can potentially give a high efficiency in terms of low production hours. Moreover it can potentially provide good precision in the fibers’ orientation. Further it can provide good quality reproducibility.

Large pressure vessels are used for CNG transportation on water. Lengths of tens of metres are not uncommon. The dimensions of these vessels, and the technology used to manufacture them, makes them valuable assets, which is worthwhile protecting in the best possible manner.

The pressure vessel 110 of Figure 2 is provided with an opening 120 (here provided with a cap or connector) for gas loading and offloading, and for liquid evacuation. It is provided at the bottom end 112 and it can be a 12 inch (30cm) opening for connecting to pipework, e.g. CNG distribution (off-load) pipework.

The vessel also has an opening 31 at the top end (111) and in this embodiment it is in the form of a manhole (30). Preferably it is at least an 18 inch (45cm) wide access manhole, such as one with a sealable cover (or more preferably a 24 inch (60cm) manhole). Preferably it fulfils ASME standards. It is provided with closing means (31),
allowing sealed closing of the opening, such as by bolting it down. The opening allows internal inspection of the vessel, such as by a person climbing into the vessel.

The pressure vessel of Figure 2 is protected by two protective pads 404 and by one protective ring 405. Each of these protective features 404, 405 comprises at least a layer of a cushioning and thermally insulating material 402 (of the kind described above) in direct contact with the external surface of the pressure vessel 115. Each of the protective features 404, 405 also comprises an outer skin or skirt of a structural rigid or semi-rigid material 406, also of the kind described above.

The geometry of the protective features 404, 405 of this second embodiment is different from the geometry of the protective feature 202, 204 of the first embodiment, although how these protective features 404, 405 work, and their purpose, are essentially the same as for the first embodiment: the padded members combine a cushioning action against the external supporting forces acting on the pressure vessel 110 with a thermal insulation in respect of the stored CNG to minimise fluctuating stresses caused by varying internal pressure forces, especially at the location of support.

The first protective feature 404 of the embodiment shown in Figure 2 comprises two protective pads, each surrounding and wrapping the vessel along a portion of a cross sectional plane, e.g. around a partial circumference and length of the vessel. The second protective feature of this embodiment comprises a single ring of a skin-covered thermally insulating material, which fully wraps around such a cross-sectional plane of the vessel, i.e. around a full circumference, it too having a certain length.

Each protective element 404, 405 is connected to the vessel's supporting means 500 so as to support, in use, the vessel 110.

Again earthing members can be provided.

Figure 3 shows a further embodiment of a CNG pressure vessel 610 supported vertically on a CNG carrier ship 710 via supporting means 700 (the latter two represented only schematically in Figure 3), so as to have an upper end 611 with a manhole aperture 630 closable and sealable by means of closing and sealing means
631, such as a bolted flange 631, and a lower end 612 with a lower aperture 620 adapted to be connected to CNG pipework for loading CNG into the pressure vessel 610 and for and offloading CNG from the same vessel 610.

Figure 3 shows schematically various differences between traditional supports or traditionally supported pressure vessels, and supports and/or pressure vessels according to the present invention. The right part of the illustrated pressure vessel 610, as defined by a vertical axis 609, represents the "prior art", and has been marked accordingly in Figure 3. The left part of the pressure vessel 610 of Figure 3 is represented and supported in accordance with the present invention by cushioned supports 660, 670. Upper cushioned support 660 and lower cushioned support 670 each comprise a layer of a cushioning and thermally insulating material 664, 674 with an outer skirt of a rigid or semi-rigid structural material 662, 672. The effect of the thermally insulating material 664, 674 and the outer skirt on the pressures/forces/stresses/strains transmitted by the supporting means 700 on the vessel 610 has been explained above. The same considerations apply to Figure 3. Figure 3, however, is provided here mainly to show the differences in the local force, pressure and deformation distributions on the pressure vessels between the prior art and the present invention.

The pressure vessel of Figure 3 is schematically represented, on the right hand side, supported by two conventional upper and lower supports 650, 651. The upper support 650 is located towards the upper end 611 of the pressure vessel 610, and the lower support 651 is located towards the lower end 612 of the vessel. As well as the supports of the present invention, the traditional supports 650, 651 can have different geometries. A known geometry is a ring. For example, in Figure 3, a ring of steel can be the support 650, which ring surrounds the pressure vessel 610 around a horizontal cross-sectional plane of the upper part 611 of the pressure vessel 610.

The pressure vessel is held firmly in position on the ship by the two supports 650, 651. The overall supporting force required to support the vessel in its position on the ship is distributed between the two supports 650, 651, and for each support the force is distributed over a small contact area between the vessel 610 and the support. Because both the pressure vessel 610 and the supports 650 are made of structural materials (or, because there is no layer providing mechanical compliance between the vessel and
each of the prior art supports 650, 651), locally the pressure vessel will be subjected to relatively high local external supporting pressures, forces, stresses or strains - see arrows 655 in Figure 3, which represent such localized interactions. Providing wider supports 650, 651 would reduce the magnitude of the local pressures 655, but because the contact between the pressure vessel and the each support 650, 651 would mainly occur along a line or small region due to the rigid coupling between the pressure vessel 610 and its prior art supports, the localised interactions would still be peaking over a small area.

The corresponding "deformation zone" 655 of the pressure vessel 610, i.e. a region of the pressure vessel subject to potential high deformation upon failure, is shown next to the lower support 651. Such deformation will be a deformation of the pressure vessel itself.

On the left hand side, by contrast, the pressure vessel 610 is schematically represented as supported by supports 660, 670 in accordance with the present invention. Each support 660, 670 comprises an inner layer of a damping and thermally insulating material 664, 674 and an outer layer of structural rigid or semi-rigid membrane 662, 672 for connecting the support 660, 670 to the supporting means 700 that support the pressure vessel on the ship 710. Assuming that the overall support force is the same as the one transmitted to the vessel 610 by the traditional supports 650, 651 of the right hand side of Figure 3, we have in this case a wider and smoother distribution of local contact pressures, forces, stresses or strains 667 acting on the surface of the pressure vessel 666 in contact with the padded supports 660, 670. Any peak forces acting on the pressure vessels while supported on the ship 710 with this inventive system will therefore be "smoothed", or spread out, so as to render them potentially less damaging than the corresponding peak forces found in the traditional supporting setup. The corresponding deformation area 675 is shown on the lower part 612 of the vessel 610, in correspondence of the lower padded support 670. The deformation area extends over a larger region compared to the region covered by the deformation zone 655 of the prior art support 651, and is a deformation of the skin or insulation material, rather than the pressure vessel itself.

The overall force handled by the support 670 is represented in Figure 3 by letter "F", and by a corresponding arrow. In the above comparison, it is assumed that F is the
same for the padded supports 660, 670 and the unpadded supports 650, 651 since they represent peak loads that occur during rough-sea transportation.

The present invention therefore achieves the advantage of a generally reduced structural failure risk for ship-based CNG pressure vessels, particularly vertically supported CNG pressure vessels. This advantage is a result of a combined interaction of the padded supports 202, 404, 405, 660, 670 with the internal pressure forces and the external supporting forces acting on the pressure vessels 10, 110, 610. The internal pressure forces are shielded, to a degree, by the supports of the present invention against possible peak loadings, and also from temperature variations of the outer environment.

In particular, the external supporting forces are cushioned and distributed over wider regions compared to the prior art, so as to be less potentially damaging on the vessel’s surface. See the top half of Figure 3, where the loading zones 667 (present invention) and 655 (conventional arrangement) are directly comparable - the loading zone is larger when using the present invention, whereby the point loadings are correspondingly smaller.

The pressure vessels can be adapted to carry a variety of gases, such as raw gas straight from a bore well, including raw natural gas, e.g. when compressed - raw CNG or RCNG, or H₂, or CO₂ or processed natural gas (methane), or raw or part processed natural gas, e.g. with CO₂ allowances of up to 14% molar, H₂S allowances of up to 1,000 ppm, or H₂ and CO₂ gas impurities, or other impurities or corrosive species. The preferred use, however, is CNG transportation, be that raw CNG, part processed CNG or clean CNG - processed to a standard deliverable to the end user, e.g. commercial, industrial or residential.

CNG can include various potential component parts in a variable mixture of ratios, some in their gas phase and others in a liquid phase, or a mix of both. Those component parts will typically comprise one or more of the following compounds: C₂H₆, C₃H₆, C₄H₁₀, C₅H₁₂, C₆H₁₄, C₇H₁₆, C₈H₁₈, C₉+ hydrocarbons, CO₂ and H₂S, plus potentially toluene, diesel and octane in a liquid state, and other impurities/species.
The invention has been described above purely by way of example. Variations in detail with respect to the above-illustrated embodiments are possible within the scope of the present invention as defined in the appended claims.
CLAIMS:

1. A device comprising a pressure vessel for transportation of CNG, the vessel comprising a vessel body adapted to receive and contain CNG, and a layer of a cushioning and thermally insulating material, external of the vessel, for thermally insulating at least a portion of the vessel, wherein the cushioning, thermally insulating material is distinct from the vessel body.

2. A pressure vessel according to claim 1, wherein the thermally insulating material is either one of, or a combination of more than one of, a foam, a polymer or an elastomer such as rubber material, or a mixture or laminate of such materials.

3. A pressure vessel according to claim 1 or 2, wherein a rigid or semi-rigid skin or skirt of structural material is in contact with at least a portion of the thermally insulating material.

4. A pressure vessel according to claim 1, 2 or 3, wherein the thermally insulating material surrounds the vessel body.

5. A pressure vessel according to any one of the preceding claims, wherein the vessel body comprises a cylindrical portion and wherein the thermally insulating material wraps at least the cylindrical portion of the vessel body.

6. A pressure vessel according to any one of claims 3, 4 or 5, wherein the skin or skirt extends around a circumference of the thermally insulating material.

7. A pressure vessel according to any one of claims 3 to 6, further comprising supporting means for connecting the pressure vessel to a hull or deck of the vessel, such that the pressure vessel can be supported in a desired position thereon, the supporting means being attached to the skin or skirt of structural material.

8. A pressure vessel according to claim 7, wherein the supporting means comprise a ring-shaped holder or bracket.
9. An apparatus for supporting CNG pressure vessels on a vehicle, the apparatus comprising:
   means for fixing the apparatus to the vehicle;
   means for supporting at least one CNG pressure vessel in a desired position on
   the vehicle;
   wherein the apparatus comprises a layer of a thermally insulating material for
   thermally insulating at least a portion of the at least one pressure vessel, said layer
   being also configured to form a cushion in the apparatus between the at least one
   pressure vessel and the supporting means when the at least one pressure vessel is
   supported by the supporting means in the apparatus.

10. An apparatus according to claim 9, wherein the apparatus is configured for
    supporting the pressure vessel substantially vertically.

11. An apparatus according to claim 9 or 10, wherein the layer of thermally
    insulating material comprises a foam, a plastic or an elastomer such as rubber
    material, or a combination thereof.

12. An apparatus according to claim 9, 10 or 11 wherein a rigid or semi-rigid skin or
    skirt of structural material is interposed between the pressure vessel supporting means
    and at least a portion of the thermally insulating material.

13. An apparatus according to any one of claims 9 to 12, wherein the thermally
    insulating material extends around the pressure vessel.

14. An apparatus according to any one of claims 9 to 13, wherein the thermally
    insulating material has a generally tubular shape.

15. An apparatus according to claim 12, 13 or 14, wherein the skin or skirt extends
    to cover the thermally insulating material.

16. An apparatus according to any one of claims 9 to 15, wherein the pressure
    vessel supporting means comprise a ring-shaped supporting member.
17. An apparatus according to claim 16, wherein the pressure vessel supporting means comprises a further ring-shaped supporting member, the two ring-shaped supporting members being spaced apart one from the other.

18. An apparatus according to any one of claims 1 to 8, when also in accordance with any one of claims 9 to 17.

19. A pressure vessel substantially as hereinbefore described with reference to any one of Figures 1, 2 or 3.

20. A naval CNG carrier vehicle comprising one or more pressure vessel in accordance with any one of the preceding claims.

21. An apparatus for supporting CNG pressure vessels on ships or boats substantially as hereinbefore described with reference to any one of Figures 1, 2 or 3.

22. A method of storing and/or transporting CNG on water comprising the steps of: loading or unloading or storing or transporting CNG into or from a pressure vessel according to anyone of claims 1 to 8, the pressure vessel being supported on a ship by an apparatus according to any one of claims 9 to 19.

23. A method of fitting out a vessel with CNG pressure vessels, the pressure vessels being in accordance with any one of claims 1 to 8, the method comprising fitting the pressure vessels onto the ship using the apparatus of any one or more of claims 9 to 19.
### A. CLASSIFICATION OF SUBJECT MATTER

**INV.** F17C1/Q0

**ADD.**

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F17C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

### Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal , WPI Data

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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### Further documents are listed in the continuation of Box C.

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### Date of the actual completion of the international search

23 October 2012

### Date of mailing of the international search report

31/10/2012

### Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel: (+31-70) 340-2040, Fax: (+31-70) 340-3016

### Authorized officer

Ott, Thomas

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