

## NATURAL GAS AS FUEL FOR SHIPS

The present invention relates to the use of natural gas as a fuel for ships and boats.

5 Emissions from boats and ships – from their engines – have long been a target of regulation, yet despite this there are still few regulations in place to control/eliminate those emissions.

10 Regulations were proposed back in 2001 and have long been fought by the marine industry. It is nevertheless believed that regulations will come into effect in the near future that will require a significant reduction in hydrocarbon or nitro oxide emissions from ships and vessels, and in particular from stern driven and inboard ships and vessels.

15 There will also most likely be a call for a reduction in carbon monoxide emissions.

Reductions of between 50 and 70% are likely to be required.

20 Due to the marine industry resisting these changes, at present such regulations are not in place or are not enforced. Nevertheless, it is likely that such regulations will soon be implemented and at present there are no reliable approaches available for achieving these reductions for ships. For this reason there has been a tendency with ships at the dockside to “cold iron” themselves to the dockside – the connecting of the ship to onshore electrical supplies. Such cold ironing, however, is not an ideal solution since it  
25 only operates at the dockside, rather than also as the ship or boat arrives at the dockside. It would be desirable, therefore, to provide an alternative means for a ship or boat to meet its electrical demands at the dockside, and possibly also in its approach to the dockside.

30 Natural gas has been explored as a potential solution to this problem since it is a relatively clean fuel to burn in engines compared to the conventional fuel – diesel. However, it is less fuel efficient than diesel, and in its most space-saving form – LNG – it requires space hungry cooling equipment since it needs to be stored at very low temperatures. Therefore, natural gas has been seen to be too space-hungry for it to be  
35 an alternative fuel for the conventional diesel.

An alternative solution is therefore required in order to comply with future regulations on emissions from watercraft.

5 According to the present invention there is provided a watercraft comprising a diesel fuel tank for fuelling general shipping requirements of the watercraft such as motoring from one location to another, wherein the watercraft additionally has a CNG pressure vessel thereon for storing CNG therein, said CNG being useable by the watercraft, from the pressure vessel, for powering an engine for coastal manoeuvring of the watercraft.

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Preferably the engine is a dual fuel engine, capable of running in a first configuration on diesel from the diesel fuel tank, and in a second configuration on CNG from the pressure vessel.

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Alternatively, there are two engines onboard the watercraft – one for running on the diesel and the other for running on the CNG.

The watercraft is preferably a ship for carrying cargo. The cargo may be CNG or containers or oil. The watercraft might instead be a passenger ferry.

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Preferably the watercraft is a CNG tanker comprises a plurality of pressure vessels for the transportation and distribution of CNG between the locations.

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Preferably the pressure vessel for supplying the engine with fuel is one of the plurality of pressure vessels, although it may instead be a dedicated pressure vessel, or a dedicated set of pressure vessels.

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CNG is typically transported within a tanker at storage pressures in excess of 200 bar. The CNG within the fuel supplying pressure vessel may likewise be stored at such pressures. A regulator can be provided between the fuel supplying pressure vessel and the engine to ensure a steady fuel-supply pressure to the engine.

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Preferably the CNG used to power the engine, when on a CNG tanker, is residual CNG, the residual CNG being extracted from a pressure vessel that has had its transportation quantity substantially offloaded therefrom, the residual CNG therefore

being the CNG that remains therein after the offload, it being at a pressure below 100 bar.

5 Preferably the CNG is extracted from the plurality of pressure vessels via pipework connected to the lower end of the or each pressure vessel.

By using CNG as the fuel for the engine near the coast, e.g. as the watercraft pulls up alongside the dockside, and while docked, there will be reduced emissions from the engines as compared to that produced by conventional diesel powered engines.  
10 Further, the emissions will be adequately clean to allow the engine to remain running while the watercraft is at the dockside for providing the watercraft's electrical requirements. As a result, the watercraft will not need to cold iron off the local power supply, although that is still an option if desired.

15 Due to the residual pressure of the CNG being significant, no fuel pump is needed to supply the CNG to the engine – it will be self-feeding.

Since CNG is stored onboard the ship substantially at room temperature, rather than at the cryogenic temperatures required for LNG, no (or only minimal) cooling or heating  
20 mechanisms are needed onboard the watercraft. Further, since only coastal operations will be fuelled by CNG, the stored volumes of CNG are controlled to a manageable level. Yet further, due to the buoyancy of CNG, and pressure vessels containing it, the presence of the pressure vessel on board the watercraft will not cause a buoyancy issue for the watercraft.

25 Preferably the pressure vessel(s) are formed of composite materials, and comprise type 3 or type 4 pressure vessels.

30 Preferably CNG is the primary cargo of the ship, with no other cargo having a greater storage volume demand compared to the CNG.

Preferably the pressure vessels are at least 15m long and at least 2m diameter.

35 The present invention also provides a method of providing propulsion on a watercraft as defined above, comprising powering the engine of the watercraft by burning CNG

stored on the watercraft when the watercraft is undertaking coastal manoeuvring, and using a different powersource for longer range journeys. Preferably the different power source is diesel and a diesel engine.

- 5        These and other features of the present invention will now be described in further detail with reference to the accompanying drawings, in which:

Figure 1 illustrates a cargo vessel for implementing the present invention; and

- 10       Figure 2 illustrates a passenger ferry for implementing the present invention;

The present invention utilises the concept of CNG as a fuel for powering an engine of a watercraft, such as a ship, not as the primary fuel, but as a secondary fuel, i.e. for coastal manoeuvring, rather than primary journeys from one location to the next.

- 15       Engines designed to run on natural gas are known in the art. Likewise pressure vessels for containing natural gas are known, even in the form of CNG, although LNG is a more conventional form of storage of natural gas.

- 20       The advantage of the use of CNG over LNG is the reduction in the equipment needed – no cooling equipment is needed since CNG is stored at high pressures, rather than low temperatures. For example, pressures of 300 to 400 bar are typical. This compares with 20 bar for LNG.

- 25       Pressure vessels for the transport of compressed fluids presently constitute four regulatory agency approved classes or types, all of which are cylindrical with one or two domed ends:

- 30       Type I.        Consists of an all metal, usually aluminum or steel, construct. This type of vessel is inexpensive but is very heavy in relation to the other classes of vessels. The entire vessel is of sufficient strength to withstand the intended pressure exerted on the vessel by a contained compressed fluid and therefore does not require any manner of strength-enhancing over-wrap, including the dry filamentous over-wrap of this invention. Type I pressure vessels currently comprise a large portion of the containers

used to ship compressed fluids by sea, their use in marine transport incurs very tight economic constraints.

5 Type II. Consists of a thinner metal cylindrical center section with standard thickness metal end domes such that only the cylindrical portion need be reinforced, currently with a composite over-wrap. The composite wrap generally constitutes glass or carbon filament impregnated with a polymer matrix. The composite is usually "hoop wrapped" around the middle of the vessel. The domes at one or both ends of the vessel are of sufficient strength to withstand the pressures developed in the vessel under normal use and are not composite wrapped. In type II pressure vessels, the metal liner carries about 50% of the stress and the composite carries about 50% of the stress resulting from the internal pressure of the contained compressed fluid. Type II vessels are lighter than type I vessels but are more expensive.

15 Type III. Consists of a thin metal liner that comprises the entire structure, that is, the cylindrical center section and the end dome(s). Thus, the liner is currently reinforced with a filamentous composite wrap around entire vessel. The stress in Type III vessels is shifted virtually entirely to the filamentous material of the composite wrap; the liner need only withstand a small portion of the stress. Type III vessels are much lighter than type I or II vessels but are substantially more expensive.

20 Type IV. Consists of a polymeric, essentially gas-tight liner that comprises both the cylindrical center section and the dome(s), all of which is currently fully wrapped with a filamentous composite. The composite wrap provides the entire strength of the vessel. Type IV vessels are by far the lightest of the four approved classes of pressure vessels but are also the most expensive.

30 As noted above, Type II, III and IV pressure vessel currently require a composite over-wrap over a vessel liner to give them the necessary strength to withstand the intended pressure exerted by a compressed fluid contained in the vessel. It is known, however, that the polymeric matrix of the composite wrap adds little or no strength to the overwrap. Thus, this invention also can be used with novel winding arrangements using a dry filamentous material that is disposed over a pressure vessel liner in a dry state and that remains in essentially a dry state (i.e. not bonded throughout with an impregnation of resin) for the life-time of the pressure vessel.

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“Essentially” in a dry state takes into consideration that, in use, particularly for marine transport of compressed fluids, the filamentous material may inadvertently become dampened by environmental moisture and the like. That is, the dry filamentous material is intended to be disposed over the vessel dry and to be dry when the vessel is put in use. Essentially dry in this context therefore does not exclude situations where the filaments/fibres are wetted by water.

The pressure vessels used for the present invention will typically be type 3 or type 4, or another form of pressure vessel utilising a full composite overwrap and either a non structural metal liner or a non metal liner or a liner used purely for the process of manufacture, i.e. a removable liner. This is because they are more lightweight than the all steel type 1 pressure vessels, whereby they are more accomodatable onboard the watercraft.

In addition to type 3 and 4 pressure vessels, new forms of pressure vessel can be applied to these various applications. These pressure vessels can be referred to as type 5, type 6, and type 7 pressure vessels. There can also be used modified versions of the various different pressure vessel types.

A type 5 pressure vessel comprises no separate liner, with the liner instead being either integral to the composite wall or it is a removable mandrel used for the forming of the wound composite wall, that mandrel then being removed after the winding process.

A type 6 pressure vessel has a steel cylindrical section and composite end-domes.

A type 7 pressure vessel has a steel liner, a composite overwrap and composite end domes.

Other variants can include type 4 pressure vessels with a metallic internal coating, which coating can improve the imperviousness of the pressure vessel to gases.

One structure for a preferred pressure vessel is a vessel having a generally cylindrical shape over a majority of its length and at least one stainless steel layer as a first layer for being in contact with the compressed fluid within the vessel, the first layer being

made of low-carbon stainless steel, and the vessel further having a further external composite layer made of at least one fiber-reinforced polymer layer that will not be in contact with the fluid contained within the vessel.

- 5      The vessel will have an opening for gas loading and offloading.

A plurality of the pressure vessels can be arranged in a module or compartment, and the pressure vessels can be interconnected for loading and offloading operations.

- 10     Preferably the vessels all have the same height, length or diameter. Some may have different heights, lengths or diameters to allow the vessels to be custom-fitted into the space provided for them within the relevant vehicle or module or compartment.

- 15     Another preferred structure for the pressure vessel is a generally cylindrical shape over a majority of its length and at least one opening for gas loading and offloading and for liquid evacuation, the pressure vessel comprising a non-metallic internal coating, a metallic liner; and at least one external fiber layer.

- 20     The non-metallic internal coating is preferably substantially inert.

The non-metallic internal coating may advantageously have a corrosion resistance of at least that of stainless steel.

- 25     The non-metallic internal coating may be selected from the group comprising: HDPE, epoxy resins, PVC, etc.

The metallic liner may be acidic gas corrosion resistant.

- 30     The metallic liner may be made of low-carbon steel.

The fiber layer may be made of fiber wound about the metallic liner.

The fiber layer may comprise carbon fibers.

This or any of the other pressure vessels may further comprise an insulating layer interposed between the liner and the composite layer (e.g. a carbon fiber layer).

The insulating layer may be a gas permeable layer.

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The fiber layer may comprise glass fibers.

The pressure vessel may further comprise a gas permeable layer interposed between the metallic liner and the fiber layer.

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The gas permeable layer may comprise glass fibers.

The pressure vessel may further comprise a gas detector connected to the gas permeable layer for detecting a gas leakage.

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The pressure vessel may be of essentially cylindrical shape, inside and outside, along the majority of its length.

Another configuration for the pressure vessel may be again a generally cylindrical shape over a majority of its length and at least one opening for gas loading and offloading. However, in this configuration the pressure vessel comprises a metallic liner, a first fiber layer external and adjacent to the metallic liner, and a second fiber layer external and adjacent to the first fiber layer. The first and second fiber layers are made of different materials.

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The metallic liner may be gas impermeable and/or corrosion resistant.

The metallic liner may be selected from the group comprising steel, stainless steel, nickel-based alloys, bi-phase steel, aluminum, aluminum alloys, titanium, and titanium alloys.

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Either or both of the fiber layers may be made of fibers wound about the metallic liner.

The first fiber layer may comprise carbon fibers.

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The second fiber layer may comprise glass fibers.

Yet another configuration can be where the pressure vessel comprises:

- at least one opening for gas loading and offloading and for liquid evacuation;
- 5 a non-metallic liner; and
- at least one external fiber layer provided on the outside of the non-metallic liner.

The non-metallic liner may be substantially chemically inert.

- 10 The non-metallic liner may have a corrosion resistance of at least that of stainless steel, in relation to hydrocarbons or CNG, and impurities in such fluids, such as H<sub>2</sub>S and CO<sub>2</sub>.

- 15 The non-metallic liner may be selected from the group comprising: high-density polyethylene, high-purity poly-dicyclopentadiene, resins based on poly-dicyclopentadiene, epoxy resins, polyvinyl chloride, or other polymers known to be impermeable to hydro-carbon gases, especially compressed natural gas polymers - the liner is desirably capable of hydraulic containment of raw gases, such as hydrocarbons and natural gas mixtures. The liner is also preferably inert to attack from such gases.

- 20 The fiber layer may be made of fiber wound about the non-metallic liner.

- The fibers in the fiber layer may be selected from the group of carbon fibers, graphite fibers, E-glass fibers, or S-glass fibers.

- 25 The carbon fibers may be coated with a thermoset resin.

- The thermoset resin may be selected from the group comprising epoxy-based or high-purity poly-dicyclopentadiene-based resins.

- 30 The vessel may further comprise a metallic internal coating provided on the inside of the non-metallic liner.

- 35 The metallic internal coating may be essentially H<sub>2</sub>S resistant, for example in accordance with ISO15156.

The metallic internal coating should preferably not present sulfide stress-cracking at the 80% of its yield strength with a H<sub>2</sub>S partial pressure of 100 kPa (15 psi), being the H<sub>2</sub>S partial pressure calculated (in megapascals – pounds per square inch) as follows:

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$$p_{H_2S} = p \times \frac{x_{H_2S}}{100}$$

where

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$p$  is the system total absolute pressure, expressed in megapascals (pounds per square inch;

$x_{H_2S}$  is the mole fraction of H<sub>2</sub>S in the gas, expressed as a percentage.

The vessel may further comprise a gas permeable layer interposed between the non-metallic liner and the fiber layer.

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The gas permeable layer may comprise glass fibers.

The vessel may further comprise a gas detector connected to the gas permeable layer for detecting a gas leakage.

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The gas permeable layer may advantageously comprise an integrated gas detection device able to warn in case of leakage from the liner. The connection to such a device may be by it being integrated into the wall of the vessel, e.g. in that layer. The device may be operated via a wireless transmission to a receiving unit cited elsewhere, e.g. in the dashboard, or on a wristwatch.

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Another form of pressure vessel that can be utilised in these ways has a body defining an internal volume in which the compressed gas/fluid can be stored and an inlet for loading the compressed gas/fluid into the vessel, the body of the vessel comprising a structural shell made entirely and solely of a fibre-reinforced filament-wound composite material comprising fibres and a matrix that is impermeable to the intended contents of the pressure vessel, i.e. the compressed gas or fluid.

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It is preferred that in use, the compressed gas/fluid will be in direct contact with an inner side of the structural shell.

5 Preferably the structural shell comprises a cylinder section and two terminations, one at either end of the cylinder section, all being made of the fibre-reinforced filament-wound composite material.

Preferably the terminations are dome-like terminations.

10 Preferably the dome-like terminations have a geodesic shape in respect of helical wrapping of fibres around the vessel.

15 Preferably the fibres of the composite material comprise at least one of carbon fibres, glass fibres or Kevlar®.

Preferably the resin of the composite material comprises at least one of a polyester resin, a vinylester resin, an epoxy resin, a phenolic resin, a high-purity dicyclopentadiene resin, a bismaleimide resin and a polyimide resin.

20 The method of manufacturing this composite pressure vessel involves the steps of providing a disposable mandrel and winding filament fibres around the disposable mandrel to form the shape of a pressure vessel, the shape including an inlet/outlet. The inlet/outlet is typically an aperture in an end thereof. There may be two apertures, one in each end. The ends are typically opposing ends.

25 The method typically involves the step of removing the disposable mandrel through the inlet/outlet after the composite is cured.

30 Preferably the method comprises the step of aggregating the filament fibres to form a tape before winding them around the disposable mandrel.

Preferably the method comprises the step of impregnating the filament fibres with a resin before winding the fibres around the disposable mandrel.

Preferably the impregnation of the fibres takes place after the fibres have been formed into a tape and by immersing the tape into a batch of resin, such as in a bath of resin.

5 Preferably the method comprises the step of curing the composite while it is around the disposable mandrel, at least to a sufficient extent for it to be self-supporting.

10 Preferably the method comprises the further the step of curing the composite and removing the disposable mandrel once the composite has been cured at least to a sufficient extent for it to be self-supporting.

Preferably the mandrel comprises ice, and the removal of the mandrel may then comprise melting the ice.

15 Preferably the mandrel comprises compacted sand, and the removal of the mandrel then may comprise shaking the sand out of the vessel.

The mandrel may comprise a scaffold, and the removal of the mandrel may then comprise collapsing the scaffold.

20 The mandrel may comprise a structure formed from a dissolvable chemical compound (such as one that is desolvable in water) and the removal of the mandrel may then comprise the dissolution of the structure to a liquid state.

25 The present invention also envisions the combination of the various optional or preferred features listed above into the other types of pressure vessel, and also the use of those so modified pressure vessels in the applications listed.

30 The present invention has been described above purely by way of example. Modifications in detail may be made to the invention within the scope of the claims appended hereto.

**CLAIMS:**

- 5 1. A watercraft comprising a diesel fuel tank for fuelling general shipping requirements of the watercraft such as motoring from one location to another, wherein the watercraft additionally has a CNG pressure vessel thereon for storing CNG therein, said CNG being useable by the watercraft, from the pressure vessel, for powering an engine for coastal manoeuvring of the watercraft.
- 10 2. The watercraft of claim 1, wherein the engine is a dual fuel engine.
3. The watercraft of claim 2, wherein the engine is capable of running in a first configuration on diesel from the diesel fuel tank, and in a second configuration on CNG from the pressure vessel.
- 15 4. The watercraft of claim 1, wherein there are two engines onboard the watercraft – one for running on the diesel and the other for running on the CNG.
5. The watercraft of any one of the preceding claims, the watercraft being a ship  
20 for carrying cargo.
6. The watercraft of claim 5, wherein the cargo includes one or more of CNG, containers and oil.
- 25 7. The watercraft of any one of claims 1 to 4, the watercraft being a passenger ferry.
8. The watercraft of any one of claims 1 to 4, the watercraft being a CNG tanker comprising a plurality of pressure vessels for the transportation and distribution of CNG  
30 between the locations.
9. The watercraft of claim 8, wherein the pressure vessel for supplying the engine with CNG as fuel is one of the plurality of pressure vessels.

10. The watercraft of claim 8, wherein the pressure vessel for supplying the engine with CNG as fuel is a dedicated pressure vessel, or a dedicated set of pressure vessels.

5 11. The watercraft of any one of the preceding claims, wherein the CNG is stored within the pressure vessel or pressure vessels at mean storage pressure in excess of 200 bar.

10 12. A method of powering a ship at a dockside comprising running an engine of the ship, the engine being CNG powered from on-board stored CNG, the engine being hooked up to an alternator/generator for producing the electrical energy demands of the ship.

15 13. The method of claim 12, wherein the CNG is stored in one or more pressure vessel onboard the ship.

14. The method of claim 13, wherein the pressure vessel(s) are formed using composite materials, and comprise type 3 or type 4 pressure vessels.

20 15. The method of claim 13 or claim 14, wherein the pressure vessel(s) are at least 15m long and at least 2m diameter.

25 16. A method of providing propulsion on a watercraft according to any one of claims 1 to 11, comprising powering the engine of the watercraft by burning CNG stored on the watercraft when the watercraft is undertaking coastal manoeuvring, and using a different powersource for longer range journeys.

17. The method of claim 16, wherein the different power source is diesel and a diesel engine.

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