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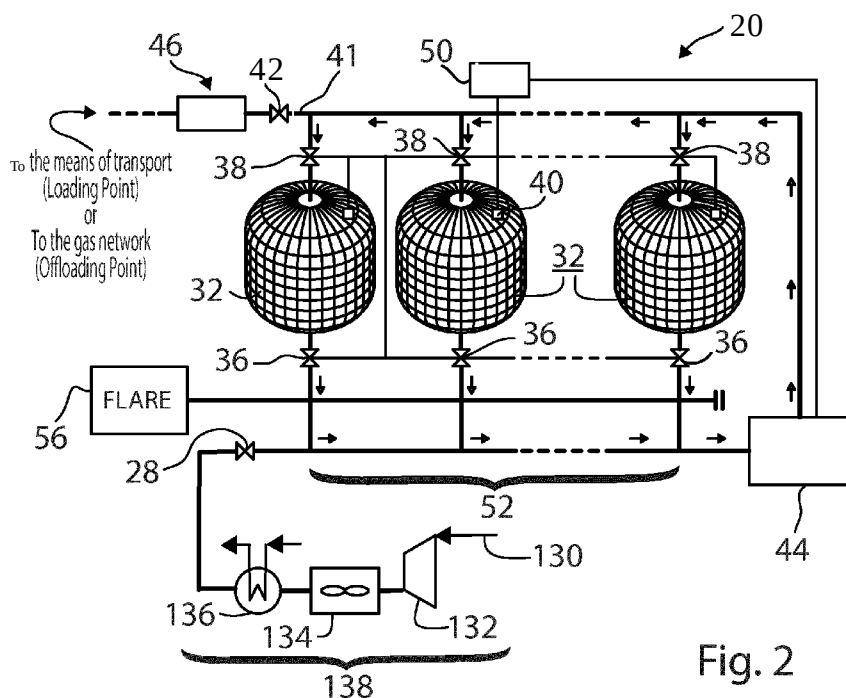


Fig. 2

(57) Abstract: A storage system for compressed natural gas which includes at least one storage vessel for storing CNG and a cooling station wherein the storage vessel is connected to the cooling station so that CNG may be stored in the storage vessel after had been passing through the cooling station and once the stored gas conditions fall out a set range, it is cooled in the cooling station, and returned to the storage vessel, wherein the storage vessel is thermally insulated from the exterior thereof thanks to the composite materials and especially glass-reinforced polymers whose pressure vessels are made.

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CNG STORE COMPRISING COMPOSITE PRESSURE VESSELS

Field of the Invention

The present invention relates to the storage of compressed natural gas (CNG). More specifically, the invention relates to a CNG store and storage system comprising pressure vessels.

Background of the Invention

Fuel gas stored in the form of CNG consists principally of methane in the gaseous state, although in some cases it may contain a liquid fraction at a high pressure.

The term CNG means compressed natural gas, be it well stream fluids, i.e. gas and liquid hydrocarbons received untreated from the source, or treated compressed natural gas - which will have fewer impurities.

CNG fluids 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: C_2H_6 , C_3H_8 , C_4H_{10} , C_5H_{12} , C_6H_{14} , C_7H_{16} , C_8H_{18} , C_9+ hydrocarbons, CO_2 and H_2S , plus potentially toluene, diesel and octane in a liquid state.

The optimum condition for the storage of CNG is a pressure of about 250 bar when measured at ambient temperature, conventionally defined as being about 15°C, or if measured at a lower temperature, i.e. about -30°C, a pressure of about 160 bar.

Compared to the conventional methods of storage of gas - at low pressure, which is done with the gas in liquid form (LNG - liquefied natural gas), the advantages of using CNG are considerable. The advantages include in particular the savings in terms of the overall investment and processing costs, in terms of the equipment needs, and also in terms of the times involved in the loading/unloading processes when the gas is transported to, or away from, the store. In particular CNG technology involves the

construction of more standardised, or simplified, loading and unloading terminals. These platforms might, for example, be off-shore platforms or buoys.

- 5 With CNG, the gas can often be loaded at the terminals at a pressure and temperature conditions which are already suitable for onward sale or delivery. With LNG, on the other hand, the offloaded LNG typically requires further processing in complex re-gasification plants prior to onwards use since the LNG is typically offloaded in liquid form and at cryogenic
- 10 temperatures. Said re-gasification facilities can be extremely costly, and can be undesirable or dangerous in environmental terms, whereby they are generally ill-suited for the European shorelines along the Mediterranean Sea, which regions are generally heavily populated, for example, the coastline of Italy.

15

CNG loading and offloading procedures and facilities depend on several factors linked to the locations of gas sources and the composition of the gas concerned.

- 20 With respect to facilities for connecting to ships (buoys, platform, jetty, etc..) it is desirable to increase flexibility and minimize infrastructure costs. Typically, the selection of which facility to use is made taking the following criteria into consideration:

safety;

- 25 reliability and regularity;

water depth and movement characteristics; and

ship operation: proximity and maneuvering.

- A typical platform comprises an infrastructure for collecting the gas which
- 30 is connected with the seabed.

- A jetty is another typical solution for connecting to ships (loading or offloading) which finds application when the gas source is onshore. From a treatment plant, where gas is treated and compressed to suitable loading
- 35 pressure as CNG, a gas pipeline extends to the jetty and is used for loading and offloading operations. A mechanical arm extends from the jetty to a ship.

Jetties are a relatively well-established solution. However, building a new jetty is expensive and time-intensive. Jetties also require a significant amount of space and have a relatively high environmental impact, specifically in protected areas and for marine traffic.

5

Solutions utilizing buoys can be categorized as follows:

CALM buoy;

STL system;

SLS system; and

10

SAL system.

The Catenary Anchor Leg Mooring (CALM) buoy is particularly suitable for shallow water. The system is based on having the ship moor to a buoy floating on the surface of the water. The main components of the system are: a buoy with an integrated turret, a swivel, piping, utilities, one or more hoses, hawsers for connecting to the ship, a mooring system including chains and anchors connecting to the seabed. The system also comprises a flexible riser connected to the seabed. This type of buoy requires the support of an auxiliary/service vessel for connecting the hawser and piping to the ship.

The Submerged Turret Loading System (STL) comprises a connection and disconnection device for rough sea conditions. The system is based on a floating buoy moored to the seabed (the buoy will float in an equilibrium position below the sea surface ready for the connection). When connecting to a ship, the buoy is pulled up and secured to a mating cone inside the ship. The connection allows free rotation of the ship hull around the buoy turret. The system also comprises a flexible riser connected to the seabed, but requires dedicated spaces inside the ship to allow the connection.

25

The Submerged Loading System (SLS) consists of a seabed mounted swivel system connected to a loading/offloading riser and acoustic transponders. The connection of the floating hose can be performed easily without a support vessel. By means of a pick up rope the flexible riser can be lifted and then connected to a corresponding connector on the ship.

The Single Anchor Loading (SAL) comprises a mooring and a fluid swivel with a single mooring line, a flexible riser for fluid transfer and a single

anchor for anchoring to the seabed. A tanker is connected to the system by pulling the mooring line and the riser together from the seabed and up towards the vessel. Then the mooring line is secured and the riser is connected to the vessel.

5

CNG technology, moreover, is generally speaking more efficient than LNG since the consumption of energy in the processing of the gas is typically much lower, which in turns leads to a smaller greenhouse gas emissions footprint.

10

MMSCF (or mmscf) is used to refer to a standardised volume of gas. It means million standard cubic feet - a standard term for quantifying a stored amount of useable CNG.

15

A standard cubic foot (abbreviated as scf) is a measure of quantity of gas, equal to a cubic foot of volume at 60 degrees Fahrenheit (15.6 degrees Celsius) and either 14.696 psi (1 atm or 101.325 kPa) or 14.73 psi (30 inHg or 101.6 kPa) of pressure. A standard cubic foot is thus not a unit of volume but of quantity, and the conversion to normal cubic metres is not the same as converting cubic feet to cubic metres (multiplying by 0.0283...), since the standard temperature and pressure used are different. Assuming an ideal gas, a standard cubic foot using the convention of 14.73 psi represents 1.19804 moles (0.0026412 pound moles), equivalent to 0.026853 normal cubic meters.

25

Common oilfield units of gas volumes include ccf (hundred cubic feet), Mcf (thousand cubic feet), MMcf (million cubic feet), Bcf (billion cubic feet), Tcf (trillion cubic feet), Qcf (quadrillion cubic feet), etc. The M refers to the Roman numeral for thousand. Two M's would be one thousand thousand, or one million. The s for "standard" is sometimes included, but often omitted and implied. We have used it above and below in most instances.

30

In general, the pressure and temperature conditions of the gas are extremely important for the overall configuration of the storage system and also for the size, weight and constructional nature of the gas storage containers (pressure vessels). In particular, due to the inherent increase in the operating/storage/transport pressures in connection with CNG, compared to LNG, there is an increased need to devise and design new

35

CNG containers, usually referred to as pressure vessels, together with the associated filling, transportation and emptying systems.

5 The pressure vessels specifically designed for sea transportation of CNG must comply with the safety criteria and requirements stipulated by international regulations, such as the ASME and IMO standards in order to be permitted to sail. These requirements also vary depending on the type of structure used therein. For example, the pressure vessels may be made of metal (e.g. steel), a polymer, a composite material or layers of different
10 materials. New vessel structures and new materials used therefor, to offer a greater or equivalent pressure resistance but at a lower pressure vessel weight, are being developed by operators in this sector.

15 It is known that the use of containers which are able to withstand pressures as high as 250 bar, and which also have large dimensions, for example diameters of 3 metres, require large wall thicknesses in order to safely contain the pressurised gas. Thus they are very heavy, especially in the case of steel vessels. Heavier vessels require a greater degree of reinforcing and support than lighter vessels. Therefore a store or storage
20 system incorporating heavier vessels is more expensive to construct and maintain than one comprising lighter vessels.

It is also known that the use of extremely high pressure levels requires the pressure vessels to be correspondingly stronger, whereupon their costs of
25 manufacture increase. Further, this can result in a pressure vessel with a complex structure or a time-consuming fabrication process. After all, such design integrity is required since in the event of a breakage or accident, the pressure vessels must be able to survive intact so as not to present a dangerous consequence.

30 The systems most widely used for the storage of CNG envisage a plurality of cylindrical containers, called vessels or pipes depending on their shape. Typically for a given purpose they have a common length and diameter, although different applications may allow them to have different diameters and lengths. Mainly they have a diameter of 1 m and a length that is
35 appropriate for the size of the ship.

These vessels or pipes are typically arranged alongside each other in

parallel arrays, either vertically or horizontally, and are most commonly made of steel (type 1) or steel plus composite body-wraps (type 2 or type 3). Both type 2 and type 3 have an inner layer wrapped with composite, but type 2 has only the cylindrical section wrapped, so the domes aren't wrapped, whereas type 3 is fully wrapped, domes included.

The vessels or pipes are designed specifically to withstand the high pressures associated with their purpose, and are fitted inside a scaffolding designed for this purpose.

10

The process for filling the said containers envisages conditioning the gas at a storage pressure and temperature, conventionally 250 bar at 15°C. The conditioning operation may be performed on-board or on land. However, costs and difficulties associated with the required piping system for the chosen approach, and where appropriate the exposure to atmospheric conditions, must be considered.

The process for emptying the containers has typically involved initially a natural expansion of the gas, which is conventionally called "natural offloading". That expanded gas is then delivered directly at a pressure value required by the delivery site. This value, however, may vary, depending upon location or application. Typically the pressure will range between 40 bar and 120 bar.

25 After the natural offloading, further gas can be offloaded using forced evacuation. In this process, the remaining or residual gas is pumped from the pressure vessel, a process often referred to as "scavenging", during which the gas may be, and generally is, recompressed - therefore more gas is removed from the pressure vessels than would have been achievable through just the process of natural offloading.

The recompression and scavenging steps involve energy usage, and consequently are often seen as being an undesirable but necessary processing step, especially where it is desired to maximise the volumetric transfer of the stored CNG, while still transferring it in a condition suitable for onward sale or distribution.

During these processing steps, the pressure and temperature values of the

CNG are sometimes modified. This is in order to facilitate the operations, or to ensure discharge at the desired temperature or pressure conditions - the expansion or recompression of CNG will ensure that the CNG is correctly readjusted to the appropriate values when discharged from the store.

It is known that the temperature of the expanding/discharged gas is a property which greatly modifies the state of that gas, and that it is a variable in practice since it is dependent upon the atmospheric conditions to which the pressure vessels are exposed, and the rate of expansion (or recompression). For example, it is known in this regard that the temperature must not drop to too low a value during the discharge, and this is to prevent or minimise liquefaction, which might otherwise occur in undesirable quantities.

Further, the temperature also determines directly the pressure of the gas, whereby it also influences the quantity of product actually transportable in a given storage volume - lower temperatures create lower pressures, therefore allowing more CNG storage for a given storage pressure in a given storage volume. Alternatively, by conditioning the gas at temperatures lower than the ambient temperature, it is possible to decrease the pressure inside the containers. For example, for the same volume with a temperature of about -30°C, the pressure of the natural gas drops from say 250 bar to about 160 bar. Therefore, a lower pressure-rated container can now store more gas by doing so at the lower temperature - instead of adding further CNG to again increase the pressure, this cooling treatment can instead be used to provide a mechanism for an alternative approach: choosing a thinner walled, and thus lighter, pressure vessel, i.e. one designed for 160 bar rather than 250 bar. Such lighter pressure vessels will be both less bulky and lighter/easier to manufacture since they have a smaller wall thickness, which again allows the storage of larger quantities of product for a given pressure vessel volume (compared to the higher temperature scenarios).

It is nevertheless necessary to appreciate that the conditioning (cooling) operation increases the complexity of the gas treatment process during the filling and storage operations.

By reducing the storage pressure compared to the conventional value of 250 bar, it is possible to limit the weight, volume and costs associated with the structure of the vessels, and also to reduce the potential danger in the event of accidents. However, the additional processing of the gas by means of refrigeration results in both greater plant investment costs and energy consumption. In connection with CNG, in particular, these processing operations may result in the need to introduce efficient cooling systems which can also be precisely controlled in order to prevent liquefaction, deliver a correct quantity of gas and also prevent dangerous increases in the pressure inside the containers.

Moreover, if the operating temperatures are lower than the ambient temperature, it is essential to provide suitable heat insulation for the container system in order to limit heat exchange with the environment surrounding the containers.

It is also known that cooling phase requires the introduction of suitable devices for preventing the change in state of the gas, such as heat exchangers and vertical separators, and also systems for controlling and modifying the pressures, such as rotary turbomachines and lamination valves.

It is also generally known that the forced-chilling processes involve difficulties in terms of incorporation within the existing piping should it also be required to recover internal or external energy, in particular thermal energy, in order to limit the use of compressors and increase the overall efficiency.

The conventional systems for temperature reduction and control applied to the transportation of gas, both onshore and offshore, can be essentially classified as follows:

a) "natural cooling" is generally performed using forced-air flows or heat exchange with the seawater, without the addition of external energy, other than the circulating currents;

b) "forced chilling" is generally performed by means of closed-circuit refrigerating machines of the compressor/evaporator type.

Although the gas transportation processes in connection with CNG are recent and are still being developed and improved, transportation processes in other sectors, such as the sector of LNG, are further
5 developed. They utilise very low operating temperatures (cryogenic), and thus include various cooling and chilling devices as well as heat exchangers, compressors, separators and other devices which assist the conditioning process and control of the liquefied gas both during filling and during storage and delivery. Also known in related sectors, such as the
10 petrochemical industry, are various specific cooling and conditioning applications. However, they do not have the same aims as the present invention.

Summary of the invention

15 According to an embodiment of the invention, there is provided a CNG storage system comprising a store having at least one pressure vessel for storing CNG at storage conditions wherein the storage conditions are different from ambient conditions and a conditioner for maintaining the
20 CNG stored in the at least one pressure vessel at the storage conditions, wherein the at least one pressure vessel has a composite structure.

In certain embodiments of the invention, the composite structure includes a composite material with at least two phases contained in it, and where the
25 two phases have substantially different mechanical properties and have respectively a reinforcing function and a continuity function, being a fibre and a matrix. Fibres may be inorganic (e.g. glass, carbon, graphite, etc.) and matrixes may be thermosets or thermoplastic polymers. The reinforcing phase made out of fibres may be aligned where most of the
30 strength is required, providing an anisotropic (different properties in different directions) but yet efficient structure.

The storage conditions may comprise a reduced pressure and or temperature. In such an arrangement, the storage conditions may
35 comprise a pressure of about 250 bar at ambient temperature (15°C). In a further embodiment, the storage conditions comprise a temperature of -30°C and a pressure of about 160 bar.

The conditioner may comprise an exchanger. In further embodiments, the conditioner further or alternatively comprises a compressor and/or a Joule-Thompson valve. In an embodiment, the conditioner includes one or more sea water exchangers.

5

In an arrangement according to the invention, CNG stored in the pressure vessels of the store is monitored by a monitoring system and transported to the conditioner when the condition of the stored CNG varies from the storage conditions by more than a predetermined amount. In an
10 embodiment, the predetermined amount is a variation in the temperature and/or pressure of no more than 1%, 2% or 5% of the storage conditions, depending on the danger potential and the manufacturing tolerances of the store used.

15 The predetermined amount may vary depending on the requirements. A smaller predetermined amount will be more energy intensive, but will also ensure fewer variations in the volume and other characteristics of the stored gas. These, and other, parameters may be altered according to operational requirements.

20

The system may comprise a pre-storage treatment unit which comprises multiple treatment steps for lowering the temperature of the fluid, the said multiple treatment steps comprising a) air-jet cooling; b) seawater cooling, and c) chilling with refrigerating cycle using a compressor/evaporator, or a
25 cryogenic cycle; wherein said treatment steps function either to decrease the working pressure of the fluid or to allow an increase in the fluid density while maintaining substantially the same working pressure.

Steps a) to c) may be carried out in sequence.

30

The seawater cooling may be carried out using a sea-water heat exchanger.

The working conditions for storage of the CNG, upon completion of the
35 filling of the one or more pressure vessel may be: temperature of -30°C, +/- 4°C and pressure of 160 bar, +/- 10 %.

The working conditions for storage of the CNG, upon completion of the

filling of the one or more pressure vessel may be: temperature of -30°C , $\pm 1^{\circ}\text{C}$ and pressure of 160 bar, $\pm 2\%$.

5 The treatment steps for lowering the temperature during filling may be arranged to adjust the incoming fluid's pressure and temperature levels to within predetermined ranges defined by minimum and maximum temperature and pressure values.

10 Treatment step a) may be arranged to adjust the incoming fluid's temperature to a temperature of between 55°C and 65°C .

Treatment step b) may be arranged to adjust the incoming fluid's temperature to a temperature of between 10°C and 20°C .

15 Treatment step c) may be arranged to adjust the incoming fluid's temperature to a temperature of between -35°C and -25°C .

20 In step c) the refrigerating fluid may be a mixture of propane and ethylene in a percentage amount of propane of between 74% and 76%, together with a complementary percentage amount of ethylene which is between 26% and 24%.

The pressure vessel may comprise:

25 a cylindrical body having a diameter and an axial length;
two cylinder ends each having an axial depth, the cylindrical body and the cylinder ends together defining a generally convex external surface and a generally concave internal surface defining an internal volume for containing the CNG; and

30 a CNG inlet/outlet,
wherein an overall length of the pressure vessel is defined by adding the axial length of the cylindrical body to the corresponding axial depths of the cylinder ends, each measured externally and excluding the length of the CNG inlet/outlet, and

35 the ratio between the overall length of the pressure vessel and the external diameter of the cylindrical body is comprised in the range between 2:1 and 1:1, and including the values of 2:1.

The store may comprise more than one pressure vessel.

At least one of the cylinder ends may be in the shape of a dome when considered in the absence of any inlet or outlet, or any neck thereof.

- 5 The dome may have a substantially constant radius about at least 90% of its radial extent. A short extent, however, may be blended with the cylindrical body to reduce stress concentrations within the material of the vessel, upon pressure loading the vessel.
- 10 Both cylinder ends may be in the shape of such a dome.

Both cylinder ends may have the same axial depth. This can be achieved with similar shapes or different shapes.

- 15 The volume and surface of the vessel may be generally axial-symmetric around the axis of the cylindrical body.

An external diameter of the cylindrical body may be between 5 and 50 metres across. 30 m is also a possible diameter.

20

The vessel may be adapted to withstand internal pressures between 50 and 160 bar. Usually the vessel will be adapted to withstand an internal pressure of at least 160 bar.

- 25 However embodiments of the present invention may also be adapted to use where the pressure is instead simply in excess of 60 bar, or potentially in excess of one of 100 bar, 150 bar, 200 bar or 250 bar, and potentially at pressures peaking at 300 bar or 350 bar. In such embodiments, "cylindrical" pressure vessels of type 3 or type 4 (e.g. pressure vessels
- 30 having a substantial cylindrical middle section with a circular cross-section).

A fibre-reinforced polymer layer may be provided around the vessel.

- The fibre-reinforced polymer layer may be provided all around the
- 35 cylindrical body of the vessel.

The fibre-reinforced polymer layer may be a hoop wrapped fibre-reinforced polymer layer.

A fibre-reinforced polymer layer may cover at least 80% of the cylinder ends of the vessel, or up to the neck of the inlet or outlet, plus the cylindrical body.

5

The cylinder ends may be geodesic domes.

The cylinder ends may have a radius that is no less than half the overall length of the vessel, that length being as defined in the statements above.

10

The fibre-reinforced polymer layer may be helically-wrapped over the cylinder ends via rotating helical hoops.

15 The wound hoops may abut against neighbouring hoops within the respective layer, thereby providing a surface covering layer of fibres. They may instead be spaced apart.

20 Multiple layers of fibre reinforcement may be built up over the surface of the vessel. Layers may alternate between hoop windings and helical windings, and the angles may vary between adjacent layers or even between spaced corresponding layers (such as spaced hoop windings). The hoop (cylindrical) section may have double the amount of fibre-reinforced polymer than the ends, due to the load distribution in the vessel structure.

25

The vessel or vessels may comprise a metallic liner. The liner may have a cross-sectional thickness in the range of between 1 and 50 mm. Other thicknesses are also possible - the thickness may be within this range, or it could be thicker than this range, especially where the liner has to withstand the winding forces - the bigger the diameter, the bigger is the risk of the liner collapsing or buckling, whereby the thicker the liner. In certain embodiments it is no more than 10mm thick (or no more than 1% of the diameter) - the liner usually will be non-structural in the final product, i.e. the windings/layers provide the vast majority of the structural strength, rather than the liner. A non-load bearing or non-structural liner is a liner capable of withstanding not more than 10% of the stresses due to the internal pressure.

30

35

Preferably the vessels comprise a polymeric layer made of 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.

- 5 Preferably the vessels comprise a wound fibrous reinforcement, the wound fibrous reinforcement comprising at least one of carbon fibres, glass fibres and Kevlar® (aramid fibres).

A fibre-reinforced polymer layer may be applied over the surface of the vessel. The layer may have a thickness of at least 100 mm for the larger
10 sized vessels, e.g. 2.5 m or more in diameter.

Description of the drawings

- 15 Figure 1 is a schematic illustration of a CNG extraction, transport and processing system;

Figure 2 is a schematic illustration of a CNG storage system according to an embodiment of the invention;

20

Figure 3 is a schematic illustration of a conditioner for incorporation into a storage system according to an embodiment of the invention;

Figure 4 shows a generally cylindrical pressure vessel;

25

Figure 5 is an enlarged cross-sectional cut-out portion from Figure 4;

Figure 6 is a schematic representation of a method of fibre-wrapping a pressure vessel, viewed from the side, the vessel being according to an
30 embodiment of the present invention;

Figure 7 is a schematic representation of a method of fibre-wrapping a spherical pressure vessel;

- 35 Figure 8 is a schematic representation of a graph illustrating in general terms the relative positioning of cylindrical and spherical pressure vessels in terms of a comparison between volume to surface area ratios and manufacturability, including an illustration of the comparative region, again

in general terms, in which the pressure vessels of the present invention may lie; and

Figure 9 is a schematic cross-sectional representation of a vessel
5 according to the present invention.

Detailed Description of Embodiments of the Invention

Figure 1 is a schematic illustration of a CNG extraction, transport and
10 processing cycle. The cycle includes extraction of the CNG at an offshore platform 10 from an underground reservoir. The CNG is then transported to a FPSO (Floating Production Storage and Offloading) 12, usually attached to the platform 10. The FPSO 12, as is known in the art, includes facilities for processing the CNG to ensure that it is in a suitable condition
15 for transport. Such processing may include dehydration unit 11, compression unit 13, storage etc. The FPSO 12 may include a storage system 15 according to an embodiment of the invention.

The cycle illustrated in Figure 1 further comprises a number of ships 14
20 which dock with the FPSO 12 to take on CNG which is then transported by the ships 14 to an offloading jetty 16. The Jetty 16 is connected to a CNG storage system 20 according to an embodiment of the invention. The CNG storage system 20 is, in turn, connected to a gas network 22 whereby the gas is transported to the various terrestrial points of use.

25 It is to be realised that the cycle illustrated in Figure 1 is provided merely by way of example. Many variations to this are found in practice. For example, the processing facilities illustrated as being located on the FPSO 12 in Figure 1 could equally be located on the offshore platform 10.

30 Importantly, the gas flow at the platform 10 cannot be interrupted. Therefore, as mentioned, it may be advantageous to include a gas storage system according to an embodiment of the invention in the platform 10, or in the FPSO 12. Similarly, it is important to maintain an uninterrupted
35 supply of gas to the gas network 22 since many users rely on this. Therefore, a supply system according to an embodiment of the invention connected to the gas supply network 22 is used. It is to be realised then that supply systems according to embodiments of the invention are

therefore able to operate as buffers for discontinuous supply of the gas (e.g. caused by the break in the supply from one ship to the next).

Figure 2 illustrates a gas storage system 20 according to an embodiment of the invention. The gas storage system 20 includes an inlet pipe 28. The inlet pipe 28 is connected to the means by which the CNG is to be delivered to the storage system 20. In the embodiment of Figure 1 this is the jetty 16, but could equally be any other source of CNG. Furthermore, in this embodiment, the CNG which enters the storage system is cooled and compressed. A gas inlet 130 is connected to a compressor 132, a fan 134 and an exchanger 136, all of which act to cool and compress the gas before it enters the inlet 28 of the system 20. The compressor 132, fan 134 and exchanger 136 form a pre-storage treatment unit 138.

The storage system 20 further comprises a plurality of pressure vessels 32. Each pressure vessel 32 comprises an inlet 38 through which CNG is introduced to the pressure vessel 32 and an outlet 36 through which CNG exits the pressure vessel 32. Furthermore, each pressure vessel 32 comprises a sensor 40 which determines the condition of the stored CNG. In this embodiment the sensor 40 determines the pressure and the temperature of the stored CNG, but in further embodiments only the temperature or only the pressure, or other characteristics of the CNG are determined.

The outlets 36 of the pressure vessels 32 are connected to a conditioner 44, the operation of which is described in further detail below. The conditioner 44 is connected to each of the inlets 38 of the pressure vessels 32. The inlets of the pressure vessels 38 are also connected to an outlet 41 through which CNG may exit the storage system 20. In the embodiment illustrated, the outlet 41 is controlled by an outlet valve 42 which is, in turn, connected to a pre-delivery treatment unit 46 which leads the gas to delivery conditions. The pre-delivery treatment unit may, in further embodiments, comprise a heater and a compressor. The composition of the pre-delivery treatment is based on where the gas storage system 20 is installed. When the gas storage system 20 is installed on FPSO 12 (upstream of the gas transport via ship) the pre-delivery treatment unit treats the gas to render it suitable for the ships involved in the transportation. On the other hand, in case where the gas

storage system 20 is connected to a gas network 22 (downstream of the gas transport via ship) the pre-treatment unit renders the gas suitable for transport by gas network 22.

5 The storage system 20 illustrated in Figure 2 further comprises a monitoring system 50 which is connected to the sensors 40, the inlet valves 38 and the outlet valves 36 of each of the pressure vessel. The monitoring system 50 monitors the output of the sensors and, when the pressure and temperature of the CNG in a pressure tanks falls below or
10 above a predetermined value, or range of values, opens the corresponding outlet valve 36 for that pressure vessel so that the gas stored in that vessel is transported to the conditioner 44 where the pressure and temperature are restored to acceptable levels.

15 Furthermore, as illustrated in Figure 2, the system comprises a flare 56 connected to the outlets 36 and controlled by the monitoring system 50. In the case of an emergency, the stored gas can be allowed to exit rapidly via the flare 56.

20 At the same time as opening the outlet valve 36 of the pressure vessel 32, the inlet valve 38 is also opened by monitoring system 50, thereby allowing CNG which was previously processed by the conditioner to enter the pressure vessel 32.

25 In this manner, the storage system 20 maintains the pressure and temperature of the CNG stored in each of the pressure vessels. The monitoring system 50 is able to control the flow into one or more of the pressure vessels 32 simultaneously.

30 Three pressure vessels 32 are shown in Figure 2. The pressure vessels 32 comprise a store 52. In further embodiments of the invention, the store may have more or fewer than three pressure vessels as illustrated by the dashed lines between the pressure vessels of Figure 2. In an embodiment, the store 52 comprises a single pressure vessel.

35 The pressure vessels which form the store 52 may include substantially cylindrical containers of varying diameter, 1m in one embodiment, and different lengths depending on the configuration of the store 52. These

high-pressure containers are arranged alongside each other in parallel and interconnected.

Embodiments of the invention may incorporate pressure vessels of the type which can be inspected. They may be arranged vertically and may, in certain embodiments, be combined in modules, by way of a non-limiting example. In an embodiment, the pressure vessels have a diameter of between 1 and 6 metres, are arranged vertically and are arranged in numbers of up to seventy units per module. Further, in an embodiment, each vessel of the module is interconnected in rows in a "series" arrangement and with each "row" connected in parallel to the main header of the module. Each module in turn is connected in parallel to the main piping system, being referred to as "multilevel".

Considering a reference case, gas would usually be stored at 250 bar and at a standard temperature, about 15 °C. With the innovative refrigerant system we get a temperature of around -30 °C and a working pressure of about 160 bar. During the loading phase (when the gas is introduced into the storage system 20), cooling and compression is carried out by the pre-storage treatment unit 138 as described above. Where sea water is provided within easy access, the exchanger 136 may operate with sea water. Once the loading of the storage system is completed, the conditioner 44 maintains the gas at a predetermined condition (e.g. -15°C, 160 bar). A suitable fluid, such as propane, periodically performs the transition from liquid to vapour passing through a compressor and a lamination valve, subtracting heat from the CNG. In a further embodiment, the pre-delivery unit, pre-storage unit and conditioner may be provided as a single compression and/or cooling unit.

Figure 3 illustrates the conditioner 44. In this embodiment, the conditioner 44 acts to compress and cool the CNG. As shown in Figure 3, treated natural gas is re-compressed by passing through a compressor 80 in order to reach a desired storage pressure value, e.g. 160 bar. Since the temperature increases as it exits the pressure vessels and since when it is compressed by compressor 80 its temperature increases as well, a cooling phase is also needed.

The conditioner 44 includes an inlet 60 whereby CNG enters the

conditioner 44 and an outlet 62 whereby the CNG exits the conditioner 44. The cooling of the CNG occurs in a cryogenic heat exchanger 64. The heat exchanger 64 includes a refrigerant and heat is exchanged between the refrigerant and the CNG in the heat exchanges 64 in a known manner to thereby cool the CNG. The cooling cycle 66 for the refrigerant is also illustrated in Figure 3.

In this embodiment, the refrigerant utilised in the cooling cycle 66 is a mixed refrigerant. The mixed refrigerant is compressed by the compressor 68 to about 20 bar, and is then condensed by the sea water exchanger 70, before being stored at about 25°C in the mixed refrigerant storage drum 72. It is then sub cooled to about 15°C by the sea water exchanger 74, and to about -30°C by the cryogenic exchanger 64. The sub cooled mixed refrigerant is then let down in the Joule-Thomson valve 76 at about 3.8 bar. The temperature of mixed refrigerant is then about -33.5°C. The cold mixed refrigerant is introduced in the cryogenic heat exchanger 64, where it will be fully vaporized, allowing it thus to cool down the natural gas down to about -30°C. The vaporized mixed refrigerant will be sent to the drum 78 before being sent back to the compressor 68.

The cooling phase of the embodiment illustrated makes use of two sea water exchangers 70 and 74. For this reason, the storage system 20 of this embodiment is located with access to sea water. In further embodiments, the sea water exchangers are replaced with alternate cooling means.

Considering working fluids in a refrigerant cycle, we note that they should offer both good efficiency and a low level of dangerousness, in terms of potential environmental impact. For example, useful working fluids could be propane, ethylene and methane. A nitrogen cycle, although the consumption is much higher, is also possible. The power necessary is higher, but it is still manageable. For example, with a liquid hydrocarbon (HC) circulation and a mixed refrigerant cycle, the power necessary for a carbon composite case storing 600 MScf is 1.3 MW. With a nitrogen cycle and nitrogen circulation, it is 4.1 MW.

Referring back to Figure 2, the conditioner 44 is connected to the monitoring system 50 which controls the functioning of the conditioner 44.

In an alternate embodiment, the conditioner 44 has a control and regulation system independent of that of the remainder of the storage system 20.

- 5 The power needed, above-mentioned, assumes the use of an insulation system designed to lose no more than about 2°C per day.

Although the cooling processes may be provided individual predetermined pressure and temperature targets, studies conducted only for a reference
10 case have established that, when using methane as the gas contained in the PVs, the following values are achievable:

a) air-jet cooling:

- Input Temperature= about 92°C;
- Output Temperature= about 60°C;
- 15 • Input Pressure= about 160 bar;
- Output Pressure= about 159.8 bar;

b) seawater cooling:

- Input Temperature= about 60°C;
- Output Temperature= about 15°C;
- 20 • Input Pressure= about 159.8 bar;
- Output Pressure= about 159.3 bar;

c) chilling:

- Input Temperature= about 15°C;
- Output Temperature= about -30°C;
- 25 • Input Pressure= about 159.3 bar;
- Output Pressure= about 158.8 bar;

From this it can be seen that in a preferred arrangement the gas pressure can be considered substantially constant through the temperature lowering
30 phases.

Further, it is to be noted that if the gas composition is different from substantially pure methane, these values (both temperature and pressure) are likely to be different, and other predetermined target values may be
35 more appropriate. Nevertheless, as a target, it would be desirable to process each step within the following margins:

Step a) 60°C +/- ΔT , where ΔT does not exceed 5°C;

Step b) $15^{\circ}\text{C} \pm \Delta T$, where ΔT does not exceed 5°C ;

Step c) $-30^{\circ}\text{C} \pm \Delta T$, where ΔT does not exceed 5°C ;

And for each step it is desirable to maintain substantially a constant output pressure value of 160 bar $\pm \Delta p$, where Δp does not exceed 10 bar, and
5 more preferably 1, 2, 3, 4 or 5 bar. These indicative target values give a suitable level of step-down for each process step, although other levels are also within the scope of the claims, such as where particular steps are suitable for greater or lesser step-changes in the temperature (or pressure).

10

The preferred fluid of CNG might include raw gas straight from a bore well, including raw natural gas, e.g. when compressed - raw CNG or RCNG, or processed natural gas (methane), or raw or part processed natural gas, e.g. with CO_2 allowances of up to 14% molar, H_2S allowances of up to
15 1,000 ppm, or H_2 and CO_2 gas impurities, or other impurities or corrosive species. Other gases, including the likes of H_2 , however, might instead be loaded or carried. The preferred use of the present invention, however, relates to CNG applications, be that raw CNG, part processed CNG or clean CNG - processed to a standard deliverable to the end user, e.g.
20 commercial, industrial or residential.

The CNG will typically be carried at a pressure of 160 bar. However embodiments of the present invention anticipate applications for use of the invention where the pressure is instead simply in excess of 60bar, or
25 potentially in excess of one of 100bar, 150 bar, 200 bar or 250 bar, and potentially at pressures peaking at 300 bar or 350 bar.

Pressure vessels suitable for the transportation and delivery of CNG can be made of various materials, and using a variety of production
30 technologies. We can list below eight different categories of pressure vessel:

1. All-steel pressure vessels (known as type 1), with the metal being used as the structure for the containment;
2. Composite Hoop-Wrapped steel tanks with structural steel heads
35 (domes) and hybrid a hybrid material body (steel + fibre-reinforced polymer, the fibre-reinforcement being in hoop sections), the hybrid material being in a load sharing condition (known as type 2);
3. Metallic liner with non-metallic structural overwrap (known as type

3). The metal liner is only there for fluidic containment purposes. The non-metallic external structural overwrap is made out of, in the preferred arrangements, a fibre-reinforced polymer; other non-metallic overwraps are also possible.

- 5 4. Non-metallic liner with non-metallic structural overwrap (known as type 4). The non-metallic liner (such as a thermoplastic or a thermosetting polymer liner) is only there for fluidic containment purposes. The non-metallic external structural overwrap can again be made out of, in the preferred arrangements, a fibre-reinforced polymer.
- 10 5. A fully non-metallic structure (no separate liner), with the non-metallic structure having been built on a substrate that is removed after the manufacturing process (known as type 5).
- 15 6. Steel body section fitted with composite heads or domes (known as type 6). The pressure vessels have a structural steel body section and fibre-reinforced polymer heads or domes fitted thereto with a sealed joint;
- 20 7. Composite Hoop-Wrapped steel bodies, with composite heads or domes (known as type 7). The pressure vessels have hybrid steel + fibre-reinforced polymer hoop wrapped body section, with the materials in a load sharing condition and fibre-reinforced polymer heads or domes fitted thereto with a sealed joint.

25 Near-Sphere shaped pressure vessels formed from a non-metallic liner with a non-metallic structural overwrap (like the type 4 above, but with the specific near spherical shape). These pressure vessels have a non-metallic liner (such as a thermoplastic or a thermosetting polymer) which serves only for fluidic containment purposes. The non-metallic external structural overwrap is typically made out of, in the preferred arrangements, a fibre-reinforced polymer.

30

Prior applications describing preferred aspects of these vessels include PCT/EP201 1/071793, PCT/EP201 1/071797, PCT/EP201 1/071805, PCT/EP201 1/071 794, PCT/EP201 1/071 789, PCT/EP201 1/071799, PCT/EP201 1/071 788, PCT/EP201 1/071 786, PCT/EP201 1/071810, 35 PCT/EP201 1/071 809, PCT/EP201 1/071 808, PCT/EP201 1/071800, PCT/EP201 1/07181 1, PCT/EP201 1/071812, PCT/EP201 1/071815, PCT/EP201 1/071813, PCT/EP201 1/071814, PCT/EP201 1/071807, PCT/EP201 1/071 801 , PCT/EP201 1/071818 and PCT/EP201 1/071796, all

of which are incorporated herein in full by way of reference. The features of the pressure vessels disclosed in those prior filings are relevant to the present invention in that they can provide the storage means for storing the fuel. As such, they can each either separately or collectively assist in
5 differentiating the present invention over prior art arrangements.

Figure 4 shows a dual layer cylindrical pressure vessel 34 for use with the store 52 of the storage system 20 of Figures 1 to 3. The shape of the pressure vessel 34 is generally in accordance with the shape of vessels
10 known from the prior art. As such, the vessel 34 has a generally cylindrical shape - the structure or body extends predominantly in one direction - the direction of the longitudinal axis of thereof, whereby the vessel resembles a cylinder rather than a sphere.

15 The vessel is formed with a wall having two layers. See Figure 5. The internal layer (i.e. the liner) 100 is made of steel, such as a low-carbon steel. The external layer (which may be a composite reinforcement) is made of a fibre-reinforced composite polymer 200, such as a carbon fibre reinforced composite material (CFRC). Other materials are possible from
20 the prior art.

The internal layer typically interfaces directly with the CNG, and the external layer is typically exposed to the external environment.

25 In this vessel 34, the thicknesses of the two layers 100, 200 are shown to be approximately equal. However, the thicknesses can be different. For example, the thickness of the inner layer - the liner 100 - can be such that it offers little or no structural capabilities during CNG transportation. Instead it would be the outer layer 200 that provides the structural
30 capabilities of the vessel, i.e. the strength needed to withstand with the elevated pressures within the vessel to which these vessels will be exposed (these vessels will be used for transporting CNG, which is loaded into the vessels at high pressure - typically such that the CNG will be in substantially gaseous form. As such, the nominal pressure that the vessels
35 of the prior art are designed to withstand is typically around 250 or 300 bar at 20°C. This can therefore be taken to be the pressure that the vessel is designed to safely withstand).

The use of metallic liners is common in the industry for such vessels since metallic liners can readily be designed to provide both CNG containment - they are typically "gas-tight", and corrosion resistance - stainless steel can be highly resistant to salt-water corrosion, and likewise chemical attack, even from many or all of the aggressive agents that would typically be present in the stored CNG - necessary since it is frequently the case that the CNG will be raw or untreated.

The vessel in Figure 4 is also shown to have two ends 84, 86, and the shapes of those illustrated ends 84, 86 are new. Further, they are different to one another.

The bottom end 86, as shown in Figure 4, accommodates an inlet/outlet aperture 120 for loading and off-loading CNG into and from the vessel 34. A 12 inch (30cm) outlet is preferred. It is typically adapted to be connected to pipework that interconnects a plurality of such vessels such as the conduit illustrated in Figure 2. The top end 84, on the other hand, accommodates a manhole 88 for internal inspection of the vessel. The manhole secured to the vessel 34 by bolts. By removing the bolts and removing the cap 90, a user can climb into the vessel for conducting an inspection. In this embodiment, the manhole 88 is an 18 inch (45cm) manhole. In a further embodiment, the manhole is a 24 inch (60cm) manhole.

The provision of different ends, and in particular the different sizes, also calls for the geometry of the top and bottom ends 84, 86 to be slightly different. While the general shape of both ends 84, 86 can be defined as being generally domed, or dome-like, albeit with a neck and a cap, the top dome is slightly deeper in the axial direction, while the bottom one is slightly more flat, or compact-looking, in the axial direction. Other arrangements, however, are possible too.

In use, the top end 84 will usually be located uppermost.

The vessel 34 therefore has a cylindrical body 92 and top and bottom ends or domes 84, 86, and they together define the overall axial, internal, length of the vessel. The cylindrical body 92 also defines the internal diameter of the vessel. As drawn in Figure 4, these give a ratio of length:diameter

(internal). The length is measured between points A-A (i.e. between the bases of the neck portions) and the diameter is measured between points B-B - located on opposite sides of the inside surface of the vessel.

- 5 Such a ratio, being more than 2.5:1, gives the vessel its cylindrical appearance. In this embodiment the ratio is about 5:1.

The vessels of the present invention can have many of these characteristics. In particular they will typically be designed to withstand
10 similar safe working pressures. However, the shape, form and construction of the vessels of the present invention will typically all be different, as described below.

Figure 6 shows a pressure vessel 110 in accordance with the present
15 invention. The vessel is more compact-looking in the axial dimension (longitudinal) compared to the pressure vessel of Figure 4. That is because the internal length to diameter ratio for this vessel is approximately 2:1. The internal length again is the internal length of the main chamber, i.e. to the base of the neck - only one neck in this embodiment. It gets measured
20 along the longitudinal axis of the vessel, according to points A-A of Figure 6. The internal diameter is measured across the middle, from the internal sidewalls, according to points B-B of Figure 6. The measurement may be a peak internal diameter if the sidewalls are not substantially perfectly cylindrical (e.g. if they have a gentle curvature).

25 In accordance with embodiments of the present invention, the vessels will have internal length to diameter ratios that fall in the range of between 1:1 and 2.5:1, or more preferably up to, and including, 2:1. Since spheres are specifically excluded, it is to be realised that the ratio of 1:1 is excluded,
30 but represents a limit. Further they will typically have a cylindrical section for defining a longitudinal axis therefor. Yet further they will typically have end-walls with internally concave surfaces (concave in both longitudinal and transverse directions as viewed from the inside). Further, one or more of those end walls will typically have an inlet/outlet, the junction to the neck
35 of which, from the end wall's internal concave surface, forms a concave/convex section (convex as viewed in the longitudinal planes and concave as viewed the transverse plane).

It is preferred also that the two end-walls 112 - left and right as seen in Figure 6 - blend smoothly into or from the cylindrical section 1000 of the vessel - see the curves 111, although they can be more angular than shown - see, for example, Figure 9. Blended junctures, however, reduce stress concentrations at those junctures upon loading the CNG into the vessels (i.e. increasing the pressure within the vessels). Blended junctures also assist with the winding operation in the first place since sharp angles are more unpredictable during the winding process, both in terms of laying down the filament, and in determining the tension needed to ensure a tight lamination, but without rupturing or damaging the filament.

In the embodiments of the present invention, as with the prior art vessels, the internal length of the vessels can be calculated as being a summation of the internal lengths of the cylindrical parts or bodies of the vessels - the body part defining a longitudinal axis for the vessels through its middle - plus the heights (or corresponding axial depths) of the domed ends at either end thereof.

Referring to Figure 6, a thin non-structural liner 1100 typically of a type 3, 4 or 8 pressure vessel, is shown to be undergoing a fibre winding procedure. The procedure includes both hoop wrapping so as to form loops defining a linear spiral and helical winding so as to form a rotating helix with sequential loops 155, 156, 157 and 158.

The basic features of the winding process of the vessel 110 are that the fibres (starting at a first free end 152 and ending at or beyond a second point 153), which may be single filaments, tapes or fabrics of fibres, or combinations thereof - are wound as coils, in a first hoop or spiral-like form 154 along the body 1000 before then passing back and forth along the body 1000, and over the two ends 111, 112, in a repeating, rotating, helical-form defined by the rotating hoops 155, 156, 157, 158. The winding process is therefore a composite or combination of the two forms discussed above in respect of cylindrical vessels and spherical vessels, namely hoop wrapping and helical winding, alternatively laying down fibre over the cylindrical portion and the end walls through a variety of angles.

In greater detail, the initial winding starts from the first end 152 - the position thereof is arbitrary, but it is shown to be close to an end or

blended corner 111 of the vessel. The winding then passes along the cylindrical section 1000 in a loop with a constant angle relative to the circumference of the vessel so as to form the spiral form 154. Then, after wrapping briefly around a first end 112, the fibre is curled through an angle to commence a return loop or arc 155 back towards the other end, perhaps again close to a blended corner 111, and then a rotating helical wrap is performed using repetitive back and forth, end-over-end, relatively rotated loops 155, 156, 157, 158 151, each of which maintains a substantially common centre of rotation that is located at a central point 150 of the vessel - this helical wrapping is continuously varying the angle of wrapping to maintain the centre of rotation at that central point 150. The helical wrapping then converts again into a hoop wrap by commencing again along the cylindrical portion in a longitudinal spiral for building up a third layer of the composite. This then continues so as to alternate layers, potentially with further layers being provided at alternative angles, until a sufficient thickness of composite has been built up for providing the desired strength for the vessel 110.

Although schematically shown to be formed with open loops, it is common practice to abut consecutive loops 154 or consecutive helices 155, 156, 157, 158 against a preceding loop or helix, whereby a surface-covering layer of loops is formed by each passage of a hoop wrap and each passage of a helical wrap (and where the fibres take the form of a tape, such abutments can cover the surface in fewer rotations).

In a technique, the fibres are impregnated with a suitable polymer or resin (a matrix) prior to winding (or even as they are being wound). As a result, the wound fibres bed down into their final position on the surface of the vessel as they are being wound thereon, i.e. already within their appropriate bed of resin - the substance that is needed to be cured for finishing off the manufacturing process. It is possible, however, that each layer of fibres might be wound onto a pre-applied resin base, with a fresh layer of resin then being applied on top of that new layer, e.g. by spraying. A further alternative might have the spraying occurring continuously. The method nevertheless comprises the building up of resin bonded layers of fibre so as to provide the desired composite structure.

The coils 154 or helical formations 155, 156, 157, 158 are provided by

delivering the fibres, filaments or tape while the vessel 110 is being rotated around the vessel's longitudinal axis. The distribution of the tape along that axis, so as to form the longitudinal coils, or rotating helix, is by means of a machine, or a machine component (such as a tape feeding head), that
5 moves linearly beside the vessel 110, parallel to the axis of the vessel 110 as the vessel 110 is rotated (although if the helical loop is to extend longitudinally, the vessel 110 would be stationary for that instant).

The tape feeding head has a variable traversal speed along that axis, and
10 likewise the vessel 110 has a variable rotation speed.

From the above it is clear that the principles of both the hoop and helical windings are in essence straightforward. Existing winding apparatus can therefore be used to perform these methods.

15 A range of hoop wrapping angles (the angles formed between the transverse plane of the vessel and the fibres themselves, at the circumference of the vessel 110) is achievable, and selectable, e.g. by varying the rotation speed of the vessel or the traversal speed of the
20 machine component (the tape feeding head).

The speed of feed of the tape from the head is varied as appropriate to ensure that the tape is applied to the surface of the vessel 110 in an appropriately tight condition.

25 In a method of winding the tape is applied in abutment to a previously applied hoop or loop, which hoop or loop will typically be the preceding hoop or loop. With tight abutments, a uniform strength characteristic can be maintained. Given this feature, it is clear that the hoops as illustrated in
30 Figure 6 - spaced-apart hoops - are not always the preferred arrangement for the laid down hoops. However, they are illustrated like that to improve the clarity of the drawing.

The control of the winding apparatus can involve varying the speed of both
35 the rotation of the vessel and the travel of the head. It will also be varied differently depending upon whether hoops are being applied in a longitudinally extending spiral or whether rotated helixes are being applied. For the hoops, the tape feeding head is traversed along the length of the

cylindrical body 1000 at a uniform speed in a first direction, with the tape being fed out of the head at a constant speed. However, upon the tape feeding head reaching the first end of the cylindrical portion 1000, the head can be arranged to slow down and then reverse direction so as

5 coordinate a looping process that lays down a loop or arc 155 of the fibres helically over that first end 112 before then moving back towards the other end of the vessel 110. The traversal speed of the head towards that other end can then be controlled so as to increase it to a speed above that of the previous traverse (i.e. the traverse in the first direction), with the tape feed

10 being correspondingly adjusted, so as to extend the helical loop around the first side of the vessel 110, in the opposite traversal direction, at a much steeper angle than the earlier hoops. The head then again slows and reverses to lay down a further loop or arc 156 around the opposite end, before then traversing in the first direction again at the increased

15 speed (for applying the continuance of the helical loop on an opposite side of the vessel 110. Continuous control of the head speed, and potentially also the rotation speed of the vessel - it may need to be slowed down to achieve the appropriate winding without causing an over-tensioning of the tape - is therefore provided for the winding machine.

20

Finally, upon completing the appropriate number of helical loops 155, 156, 157, 158, the apparatus can return to its mode for providing a fresh hoop wrap 154 along the cylindrical body 1000 of the vessel 110.

25 Each hoop wrap layer may be provided with different angles to the previous hoop wrap layer, although it is preferred to maintain a constant angle for each hoop-wrap layer.

The ends 112 of the cylindrical vessel 110 have the general shape of

30 domes. To facilitate the helical wrapping thereof, those domes are preferably geodesic surfaces with respect to one another, i.e. they subscribe a common circle, or they are geodesic compatible - their respective radiuses are no smaller than half the distance between the two surfaces, as measured through the central point 150 of the vessel 110.

35 The minimum radius allowed for the domes, therefore, while still having a geodesic or geodesic-compatible configuration according to the above definition, is half the length A-A, as shown in Figure 6, assuming a constant radius is provided for those surfaces. Note that any rounding of

the juncture between those surfaces and the cylindrical body should be kept to a minimum to maximise the extent of those geodesic or geodesic compatible surfaces, although some rounding is still preferred to reduce the degree of stress concentration occurring at those junctures.

5

The advantage of these geodesic or geodesic-compatible surfaces for the ends 112 is that the helical winding of the fibres 155 around the domes is more easily achievable. That is because they can be wound under tension without the tendency to slip off the sides of the domes - the fibres will tend
10 either to stay in position on the surfaces after winding even though tension is being applied to them, or else they will tend to slip only towards the centre of the ends - the latter situation occurring with the geodesic compatible surfaces. With the latter arrangement, the windings are applied so as to all intersect the centre of the ends 112, or close thereto, such as
15 against the neck of an outlet 160, or against a winding already abutting there against (or its most available neighbour), thereby having an arrangement wherein each subsequent winding will tend to be forced to abut tightly against the earlier, more central winding, thus providing a stable, yet tightly arranged, surface covering for the end in question. The
20 windings, by being stable, simply will not tend to slip off the sides of the domes. Such slipping would tend to occur, however, if the radius of the ends is smaller than half the internal length of the vessel.

The optimum geodesic effect is achieved with the surfaces subscribing a
25 common circle - perfectly geodesic conditions, whereupon the windings will be windable across subsequent ends without passing through the centre of those ends, while still not tending to slip off the ends.

The inlet 160 of the vessel can also be composite wrapped using the
30 winding machine, although this is usually done at a later stage, and with a different apparatus. Initially, therefore, this part 160 of the vessel 110 is not wrapped at the same time as the wrapping of the cylindrical body 1000 and the domed ends 112.

35 In Figure 7, an alternative winding process is shown. A stainless steel liner 210 having a generally spherical shape is being wrapped with fibres 315. As usual, a portion of the sphere in correspondence with an inlet/outlet aperture 230 is left free of the fibres 315. Nevertheless, the wrapping of

the fibres 315 around the spheres is difficult since several degrees of rotation thereof are required.

5 The process is achieved in Figure 7 by the provision of a fibre delivering head 300 positioned on a supporting arc 311, rather than on the linear line as discussed above. The fibre delivering head 300 can therefore move 301 up and down the arc 311.

10 Further, the supporting arc 311 can rotate 313 around its own supports 312.

The spherical vessel itself is also positioned on rotating supports (not shown), so that it can also be rotated 211 around an axis. In the embodiment shown, that axis is a vertical axis.

15 In other embodiments, the spherical vessels can be filament wrapped using known three dimensional fibre delivering heads.

20 Fibre wrapping around spherical vessels using these machines follows a rotating helical pattern 316, similar to the helical patterns discussed above for the vessel of Figure 6. The fibres are wrapped in a series of connecting coils having a radius according to the circumference of the sphere on which the fibres are being laid. They are therefore centred upon the middle 350 of the sphere. This is so that they will not tend to slip off the surface of the sphere (similar to the geodesic situation discussed above) under the applied tension thereof.

30 As discussed above, more fibres are necessary per unit of required reinforcement in this type of vessel - a spherical vessel, due to the omnidirectional curvature of the walls of the vessel. The windings therefore are applied across multiple layers, potentially with multiple differing angles for the windings in each consecutive layer across the surface of the sphere. The multiple axles and the arc 311 facilitate this.

35 Figure 8 is a chart illustrating the relative positioning of generally spherical pressure vessels (top half), generally cylindrical pressure vessels (bottom half) and pipes (bottom line) comparing them to their ease of manufacture (x-axis).

Spherical pressure vessels are provided in the top half - large y-axis value - since they have the highest volume to surface area ratio. However, spherical vessels are relatively difficult to manufacture, for the reasons
5 already given, and hence they are indicated towards the left hand side of the chart - they are given a low x-axis value representing their lack of ease of manufacturability.

Cylindrical vessels are relatively easy to manufacture, due to the cylindrical
10 body being easy to wrap. This gives them a higher x-axis value than spherical vessels. However, they are not ideal in terms of volume-to-surface ratio. They are therefore awarded a lower y-axis value than spherical vessels.

15 Finally, pipes are even easier to manufacture than cylindrical vessels - no end-caps need to be made. They therefore score highly on the ease of manufacturability. However, their typically narrow cross section makes them inefficient in terms of volume to surface area ratios. They therefore appear very low down relative to the y-axis.

20 The vessels of embodiments of the present invention preferably are sized and shaped to occupy, in the chart of Figure 8, an intermediate position between the spherical vessels and the cylindrical vessels. This is shown by the cloudy area labelled "optimised spheres". The vessels of embodiments
25 of the present invention are therefore relatively compact looking pressure vessels, which are clearly neither spherical vessels, in that they comprise a substantially cylindrical portion, nor cylindrical vessels, since they are too short relative to their diameter (having a ratio of between 2:1 and 1:1 - internal length to internal diameter, including 2:1, but excluding 1:1).

30 A further example of a vessel 410 in accordance with an embodiment of the present invention is shown in Figure 9. Here the ratio between the length 412 and the depth 411 is approximately equal to 1.05.

35 In addition to measuring internal dimensions, external dimensions may be used. After all, they are easier to measure when access is not granted to the inside of the vessels. Again the neck of the inlet/outlet(s) are ignored. According to a further aspect of the invention, therefore, it is the external

dimensions that have the ratio of between 2:1 and 1:1, including 2:1, but excluding 1:1.

5 The vessel 410 of this final embodiment is made of a single layer of structural steel, with a thickness determined by the required safe maximum working pressure for the design of the vessel 410.

10 It is possible for vessels to be provided for high-pressure applications or low pressure applications. Similarly sized vessels may therefore be provided with different pressure ratings, dependent upon the strength of the walls, etc, of the vessel. In this last embodiment, the vessel 410 might be designed for middle-level pressures, which may be, for example, pressures up to 150 bar.

15 The vessel's body can be manufactured like a pipe, with the two end domes 415, 416 being welded thereon. One of the end domes is provided with an inlet/outlet aperture 420.

20 In the embodiment of Figure 9, the external diameter D of the vessel 410 measures 2 m and the length L of the vessel is about 2.25 m. The wall thickness of the steel is perhaps no more than 120 mm.

25 In other embodiments, the diameter of the vessel might be up to 50m - these vessels are large due to the large volume of CNG being stored therein.

30 The vessel of Figure 9 is a relatively easy-to-manufacture, end-capped cylindrical body, thereby representing a relatively inexpensive steel vessel for the storage of CNG. It has a significantly advantageous volume-to-surface area ratio and it follows that it is particularly suitable for applications in which large quantities of CNG must be stored.

35 The volume can be increased by lengthening the cylindrical section, and by increasing the diameter. However, if a larger diameter is needed, then the pressure-rating of the vessels would need to be re-assessed - thicker steel may be needed.

These vessels - to be known as optimised spheres, offer a design that is

particularly well suited to large capacity and midrange pressure applications in the sector of CNG storage and/or transportation.

5 Because of the presence of a cylindrical intermediate portion, the vessel of Figure 9 would also be relatively easy to hoop-wrap with reinforcement fibres, thereby increasing the strength without proportionally increasing the weight of the vessel - composite reinforcement is lighter than steel.

10 The convenience of the so-called optimised spheres is in essence the result of the combination of a relatively high volume-to surface-ratio with the retention of a cylindrical axis, whereby they are more readily manufactured, without undue cost.

15 In place of metal liners, plastic liners can be used, such as liners made of High Density PolyEthylene or high-purity poly-Dicyclopentadiene. A polymeric/plastic liner would also provide additional thermal insulation compared to a metal liner.

20 Further, the liner can be replaced with a removable liner, or an internal, dismantlable scaffold-type liner, wherein the liner is removed after winding and the resulting composite itself offers the complete vessel.

25 The vessels disclosed herein can store 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 H_2 , or CO_2 or processed natural gas (methane), or raw or part processed natural gas, e.g. with CO_2 allowances of up to 14% molar, H_2S allowances of up to 1,000 ppm, or H_2 and CO_2 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
30 - processed to a standard deliverable to the end user, e.g. commercial, industrial or residential.

35 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

1. A compressed natural gas (CNG) storage system comprising a store having at least one pressure vessel for storing CNG at storage conditions wherein the storage conditions are different from ambient conditions and a conditioner for maintaining the CNG stored in the at least one pressure vessel at the storage conditions, wherein the at least one pressure vessel has a composite structure.
2. The storage system according to claim 1 wherein the storage conditions comprise a reduced pressure and or a reduced temperature.
3. The storage system according to claim 2 wherein the storage conditions comprise a pressure of about 250 bar at ambient temperature 15°C.
4. The storage system according to claim 2 wherein the storage conditions comprise a temperature of -30°C +/- 4°C and a pressure of about 160 bar +/- 2%.
5. The storage system according to any preceding claim wherein conditioner comprises an exchanger.
6. The storage system according to claim 5 wherein the conditioner further comprises a compressor and/or a Joule-Thompson valve.
7. The storage system according to any preceding claim further comprising a monitoring system for monitoring CNG stored in the pressure vessels and wherein the storage system includes a compressor for transporting the CNG to the conditioner when the condition of the stored CNG varies from the storage conditions by more than a predetermined amount.
8. The storage system according to claim 7 wherein the compressor further acts to re-pressurise the CNG.
9. The storage system according to any preceding claim wherein the conditioner comprises a heat exchanger and/or fridge for chilling the CNG

10. The storage system according to claim 8 or claim 9 wherein the heat exchanger and/or the fridge operate a refrigerating cycle using a compressor/evaporator, or a cryogenic cycle.
11. The storage system according to any preceding claim further comprising a pre-storage treatment unit, the pre-storage treatment unit comprising multiple treatment steps for lowering the temperature of the fluid, the said multiple treatment steps comprising a) air-jet cooling; b) seawater cooling, and c) chilling with refrigerating cycle using a compressor/evaporator, or a cryogenic cycle; wherein said treatment steps function either to decrease the working pressure of the fluid or to allow an increase in the fluid density while maintaining substantially the same working pressure.
12. The storage system according to claim 11 wherein steps (a) to (c) are carried out in sequence.
13. The storage system according to claim 11 or claim 12 wherein the treatment steps for lowering the temperature during filling are arranged to adjust the incoming fluid's pressure and temperature levels to within predetermined ranges defined by minimum and maximum temperature and pressure values.
14. The storage system according to any of claims 11 to 13 wherein step (a) is arranged to adjust the incoming fluid's temperature to a temperature of between 55°C and 65°C.
15. The storage system according to any of claims 11 to 14 wherein treatment step (b) is arranged to adjust the incoming fluid's temperature to a temperature of between 10°C and 20°C.
16. The storage system according to any of claims 11 to 15 wherein treatment step (c) is arranged to adjust the incoming fluid's temperature to a temperature of between -35°C and -25°C.
17. The storage system according to any of claims 11 to 16 wherein, in step (c) the refrigerating fluid may be a mixture of propane and ethylene in a percentage amount of propane of between 74% and 76%, together with a complementary percentage amount of ethylene which is between 26% and 24%.

18. The storage system according to any preceding claim wherein the store comprises more than one pressure vessel.

19. The storage system according to any preceding claim wherein the pressure vessel comprises:

5 a cylindrical body having a diameter and an axial length;

two cylinder ends each having an axial depth, the cylindrical body and the cylinder ends together defining a generally convex external surface and a generally concave internal surface defining an internal volume for containing the
10 CNG; and

a CNG inlet/outlet,

wherein an overall length of the pressure vessel is defined by adding the axial length of the cylindrical body to the corresponding axial depths of the cylinder ends, each
15 measured externally and excluding the length of the CNG inlet/outlet, and

the ratio between the overall length of the pressure vessel and the external diameter of the cylindrical body is comprised in the range between 2:1 and 1:1, and including the
20 values of 2:1 .

20. The storage system according to claim 19 wherein at least one of the cylinder ends is in the shape of a dome when considered in the absence of any inlet or outlet, or any neck thereof.

21. The storage system according to claim 20 wherein the
25 cylinder ends are geodesic domes.

22. The storage system according to claim 19 or 20 wherein the dome has a substantially constant radius about at least 90% of its radial extent.

23. The storage system according to claim 21 wherein both
30 cylinder ends are in the shape of such a dome wherein both cylinder ends have the same axial depth.

24. The storage system according to any preceding claim wherein the at least one pressure vessel comprises a fibre-reinforced polymer layer provided around the vessel.
25. The storage system according to claim 24 wherein the fibre-reinforced polymer layer is a hoop wrapped fibre-reinforced polymer layer.
26. The storage system according to claim 25 wherein multiple layers of fibre reinforcement are built up over the surface of the vessel and wherein layers alternate between hoop windings and helical windings, and the angles vary between adjacent layers or between spaced corresponding layers.
27. The storage system according to any one of claims 1 to 15 wherein the at least one pressure vessel comprises a near-sphere wrapped with glass fibres.
28. A method of storing CNG comprising:
- storing CNG in at least one pressure vessel having a composite structure at storage conditions wherein the storage conditions are different from ambient conditions; and
- for maintaining the CNG stored in the at least one pressure vessel at the storage conditions.
29. The method according to claim 28 wherein the storage conditions comprise a pressure of about 250 bar at ambient temperature 15°C.
30. The method according to claim 28 or claim 29 further comprising monitoring CNG stored in the pressure vessels and transporting the CNG to the conditioner when the condition of the stored CNG varies from the storage conditions by more than a predetermined amount.
31. The method according to any of claims 28 to 30 further comprising multiple treatment steps for lowering the temperature of the fluid, the said multiple treatment steps comprising a) air-jet cooling; b) seawater cooling, and c) chilling with refrigerating cycle using a

compressor/evaporator, or a cryogenic cycle; wherein said treatment steps function either to decrease the working pressure of the fluid or to allow an increase in the fluid density while maintaining substantially the same working pressure.

- 5 32. The method according to claim 31 wherein steps (a) to (c) are carried out in sequence.

33. The method according to claim 31 or claim 32 wherein the treatment steps for lowering the temperature during filling are arranged to adjust the incoming fluid's pressure and temperature levels to within
10 predetermined ranges defined by minimum and maximum temperature and pressure values.

34. The method according to any of claims 28 to 33 wherein step (a) is arranged to adjust the incoming fluid's temperature to a temperature of between 55°C and 65°C.

- 15 35. The method according to any of claims 28 to 34 wherein treatment step (b) is arranged to adjust the incoming fluid's temperature to a temperature of between 10°C and 20°C.

36. The method according to any of claims 28 to 35 wherein treatment step (c) is arranged to adjust the incoming fluid's temperature to
20 a temperature of between -35°C and -25°C.

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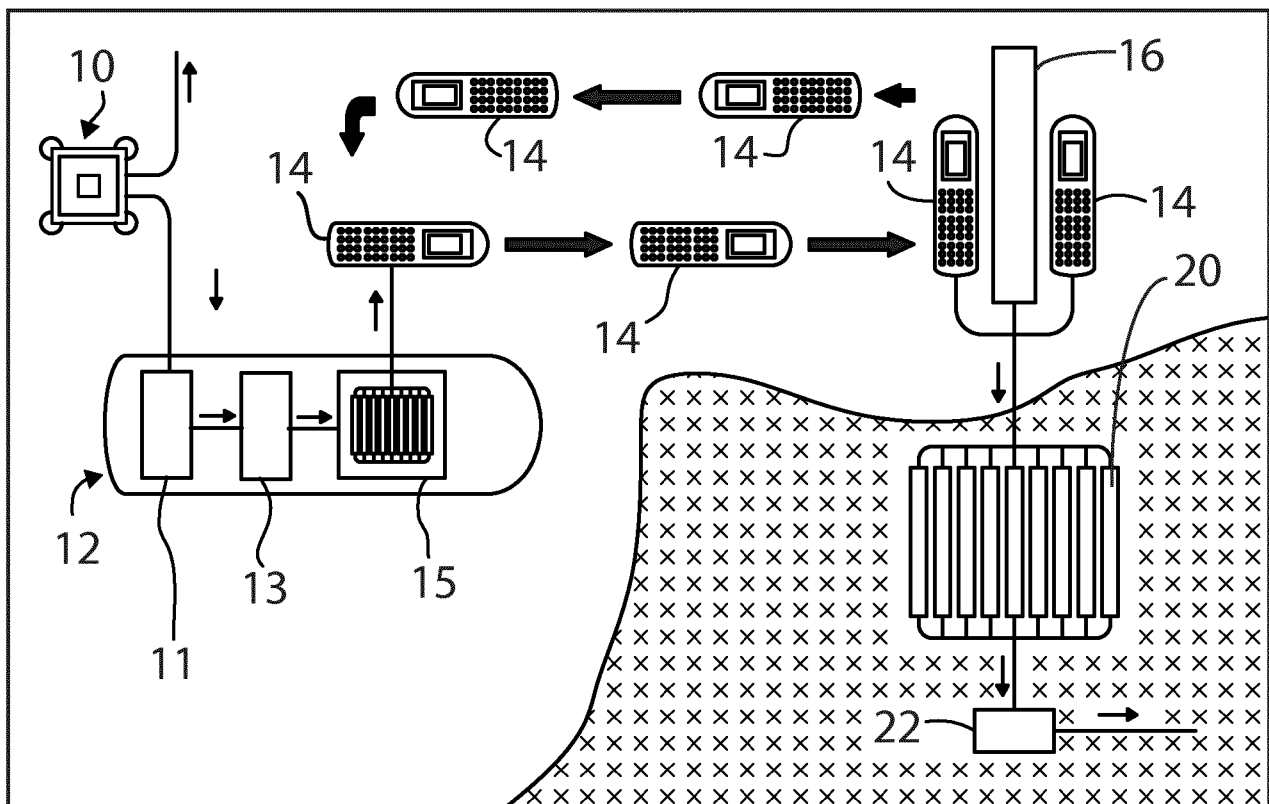
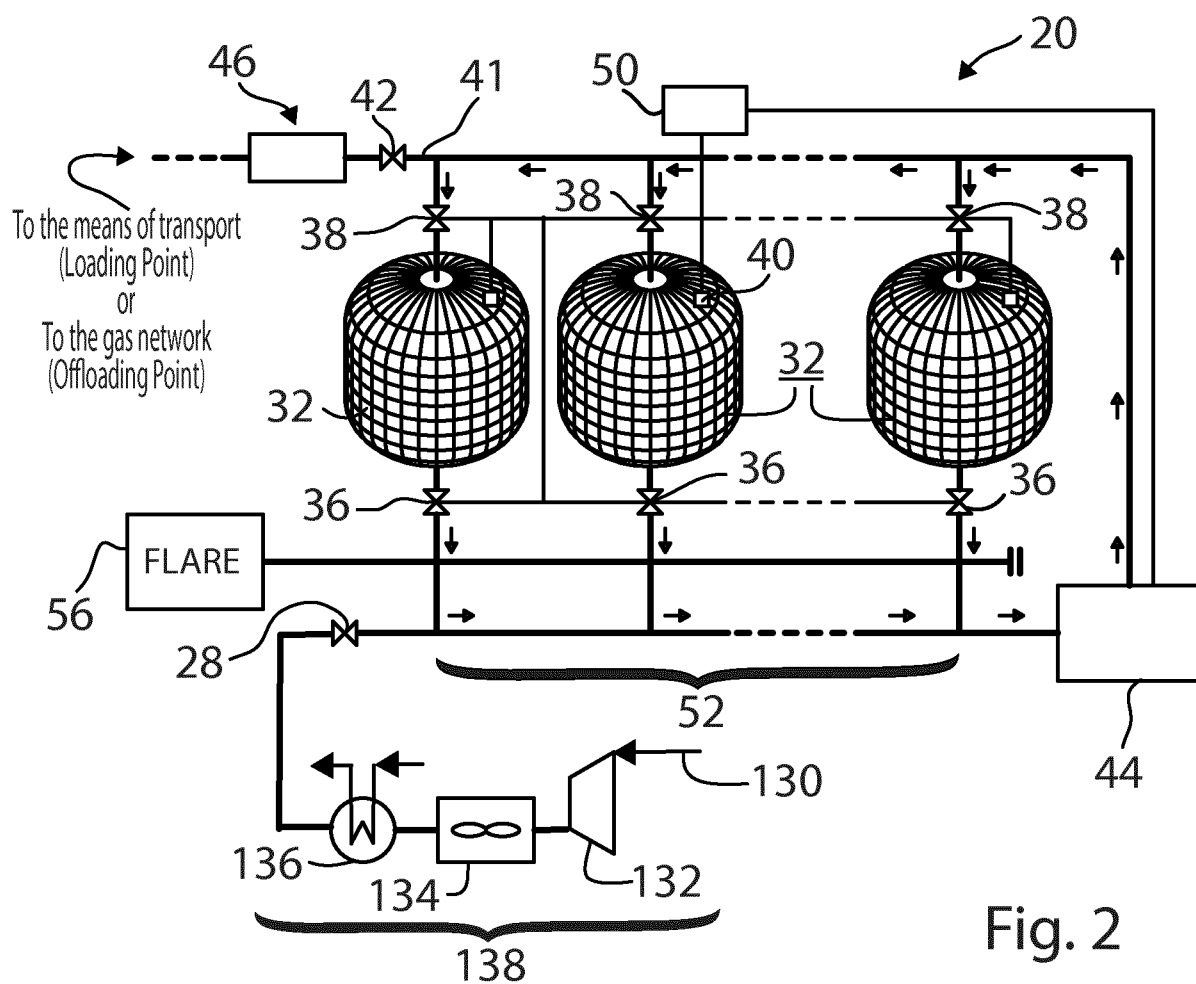


Fig. 1



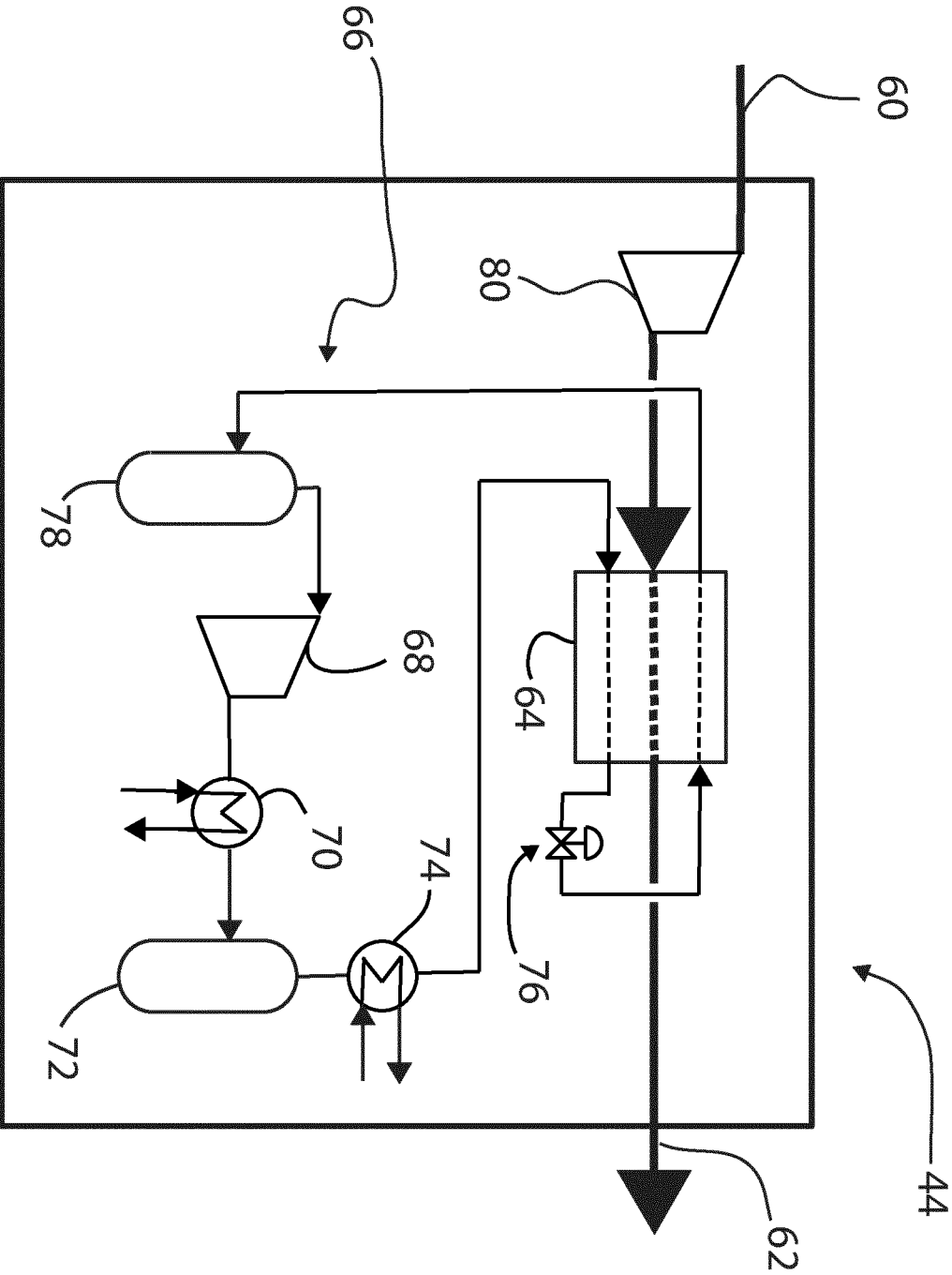
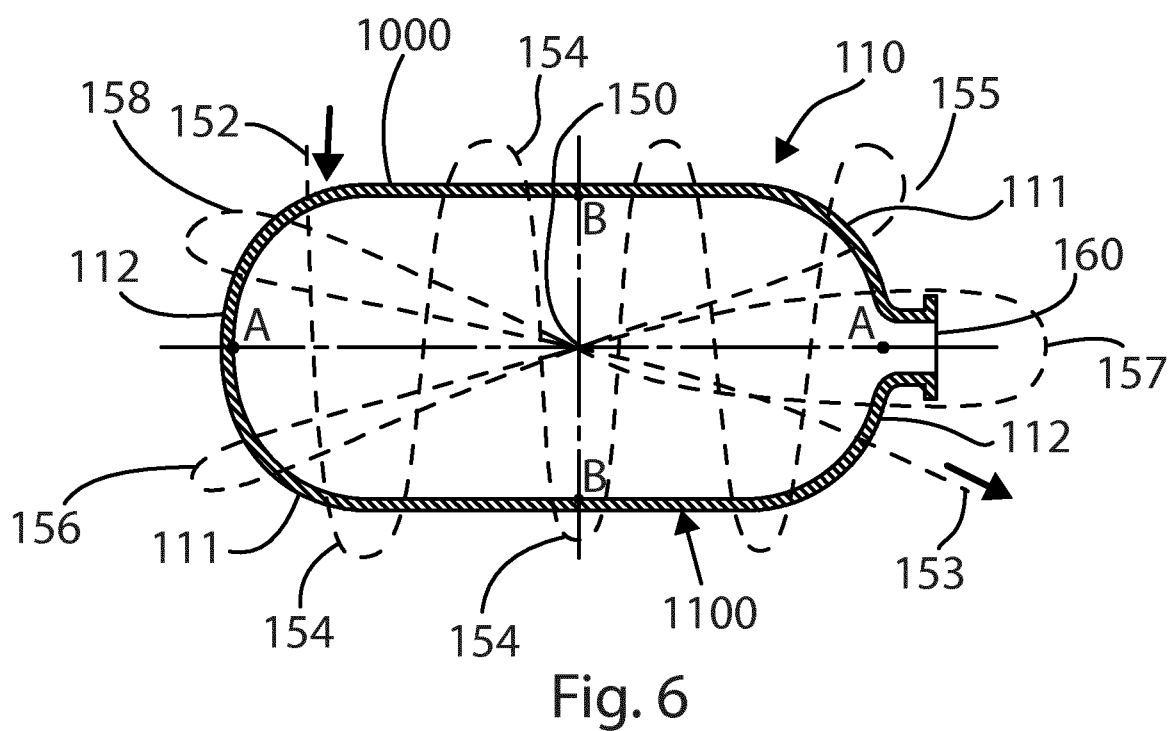
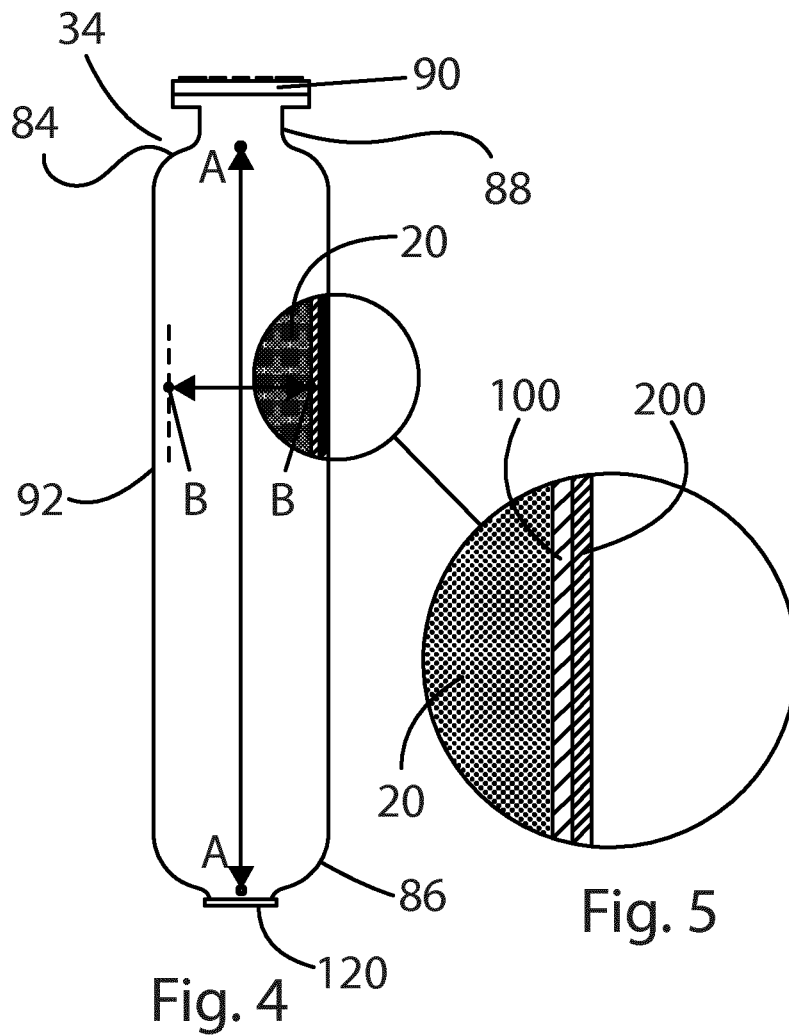


Fig. 3

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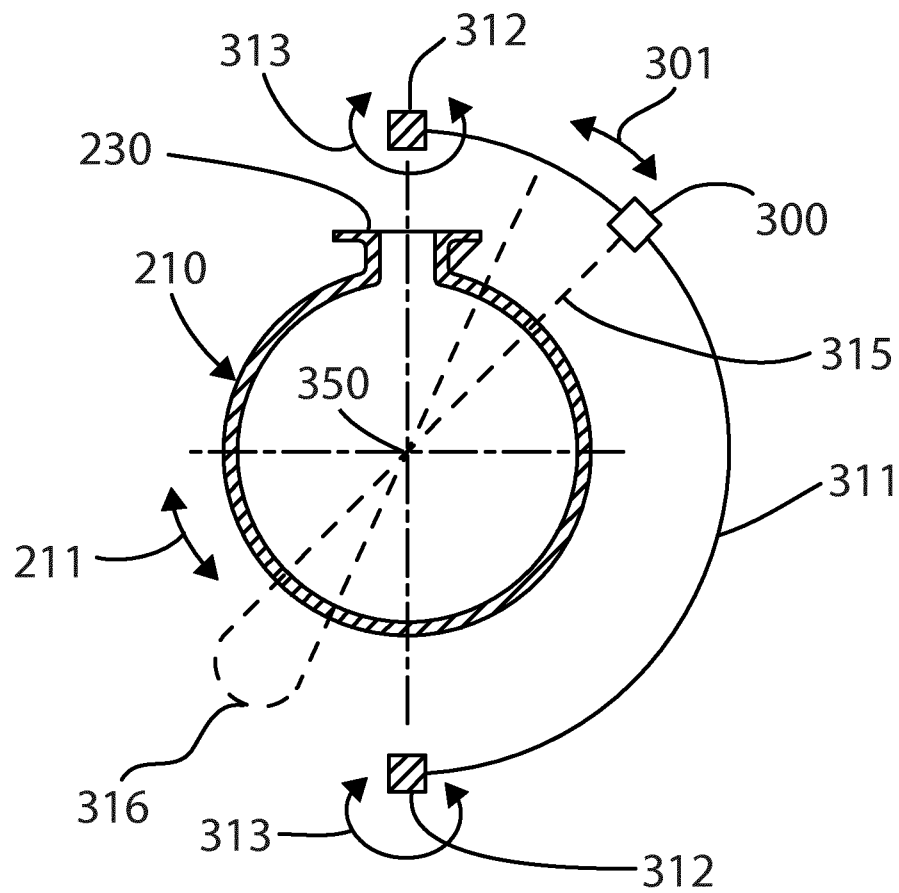


Fig. 7

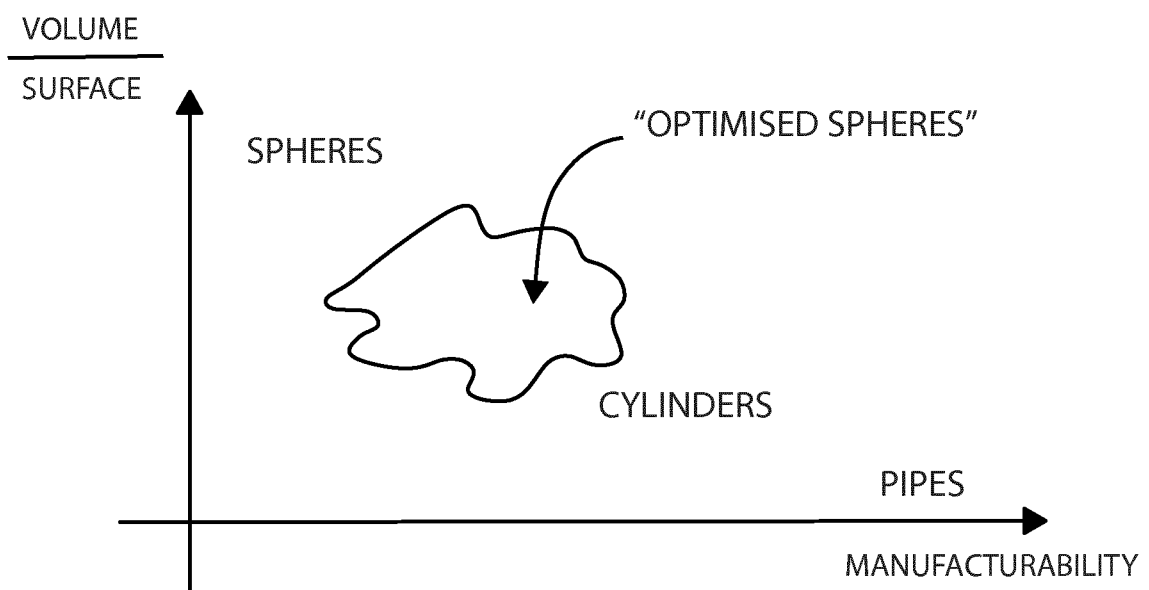


Fig. 8

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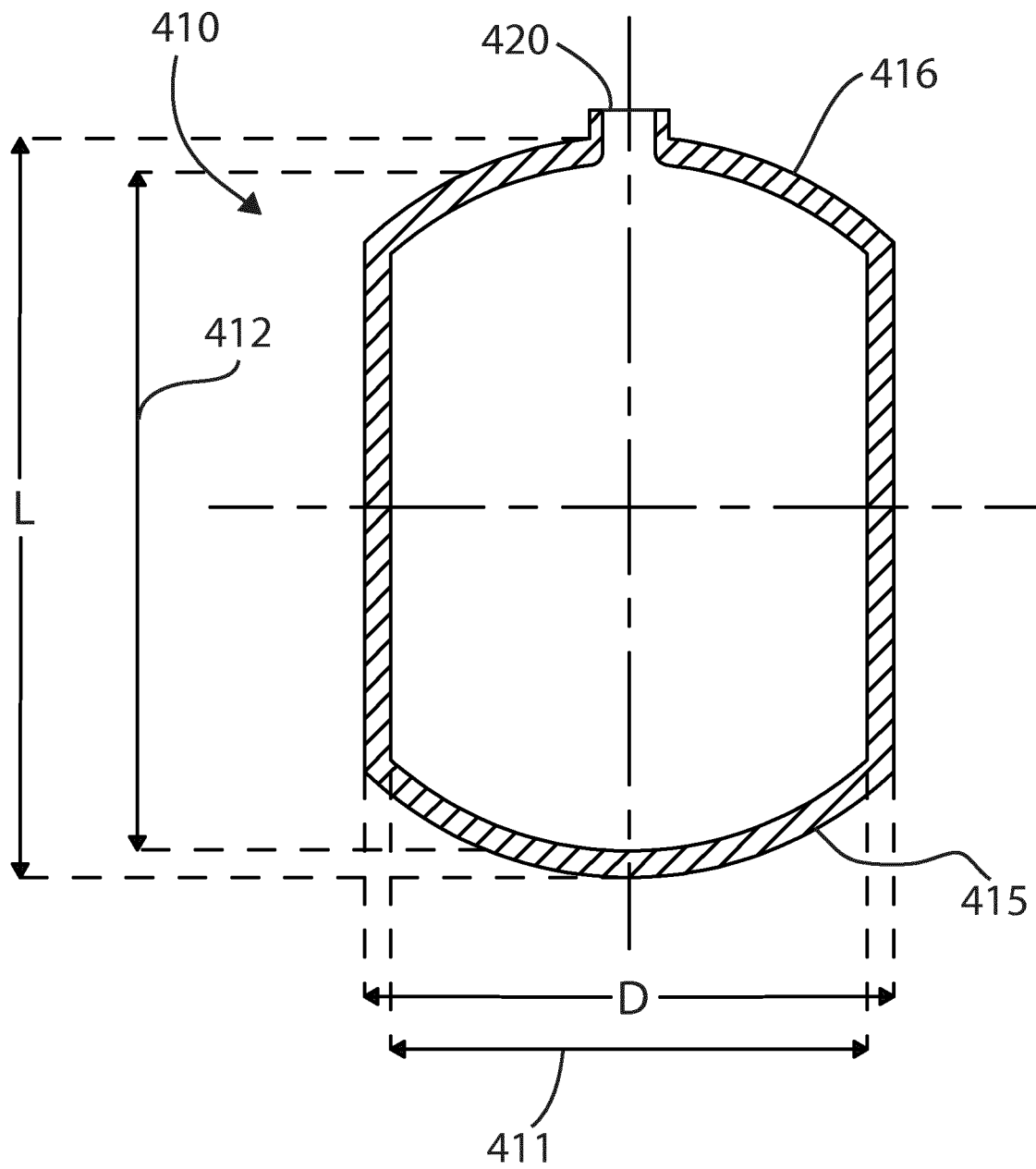


Fig. 9