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(71) **Applicant**: **BLUE WAVE CO S.A.** [LU/LU]; 4, rue de la Grève, L-1643 Luxembourg (LU).

(72) **Inventors**: **NETTIS, Francesco**; Flat A, 14, Chesham Place, London SW1X 8HN (GB). **BERGAMIN, Giuseppe**; 23 Via Cesare Pavese, I-10017 Montanaro (TO) (IT). **MOTTA, Luca**; 57 via V.Veneto, I-22060 Carugo(Co) (IT). **MUSSARDO, Domenico**; via Mazzini, 38, I-73010 Sogliano Cavour (LE) (IT). **NISO, Gianfranco**; 63-65 rue de Merl, L-2146 Luxembourg (LU). **REDONDI, Paolo**; 18 via Turati, I-24020 Gorle (BG) (IT). **ROSSI, Riccardo**; 14 Piazza Po, I-20144 Milano (Mi) (IT). **TOMASELLI, Vanni Neri**; 46 rue d'Anvers, L-1130 Luxembourg (LU).

(74) **Agent**: **WATTERSON, Peer Marten John**; B.P. 1775, L-1017 Luxembourg (LU).

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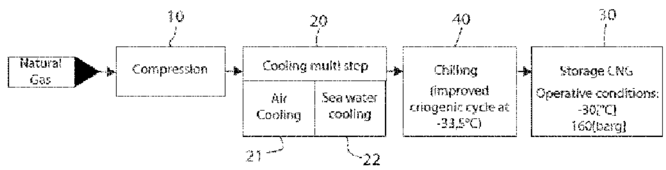

Fig. 1b

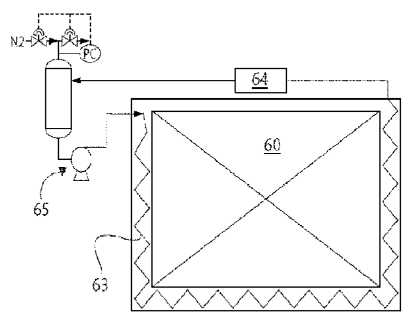

Fig. 3

(57) Abstract: Conditioning a fluid in the gaseous state by cooling it, for the sea transportation of CNG, during filling (fig. 1b) and during storage (fig. 3, 4) inside containers of the vertical pressure-vessel type, including multiple treatment steps for lowering the temperature, including a) air-jet cooling; b) seawater cooling using an exchanger for the seawater/gas, or seawater cooling; c) chilling with refrigerating cycle using an improved compressor/evaporator, or cryogenic cycle; where said treatment steps are combined with the aim to decrease the working pressure carrying the same quantity of gas or increase the gas density (so the capacity) maintaining the same working pressure; and where the gas stored and transported inside the said pressure vessels is thermally insulated from the exterior thereof.

WO 2014/086413 A1

INTEGRATED AND IMPROVED SYSTEM FOR SEA TRANSPORTATION OF COMPRESSED NATURAL GAS IN VESSELS, INCLUDING MULTIPLE TREATMENT STEPS FOR LOWERING THE TEMPERATURE OF THE COMBINED COOLING AND CHILLING TYPE

[0001] The present invention relates to a novel system for sea transportation of compressed natural gas, or "CNG", in particular applied to the operation of filling containers of the pressure-vessel type, and usually when they are arranged vertically. The invention includes multiple treatment steps for lowering the temperature, the steps being of the combined cooling and chilling type, with the aim to decrease the working pressure, while still carrying the same quantity of gas, or to increase the gas density (and thus the storage capacity) while maintaining the same working pressure.

Field of application

[0002] The present invention is most suitable to the application thereof to the marine transportation of CNG, usually at sea. CNG is an acronym for compressed natural gas.

Fuel gas transported by sea 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 optimum condition for transportation 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.

[0003] Compared to the conventional methods of transportation 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. 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.

With CNG, the gas can often be offloaded 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 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. Consider, for example, the coastline of Italy.

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.

[0004] CNG technology is relatively new compared to LNG, and it is still being rapidly developed. It is considered to possess great potential, in particular for short to medium distance applications, such as often occurs in the region of the Mediterranean Sea. For these short to medium distance applications, it is increasingly being recognised that it is likely to be more economical to use than LNG owing to the greater ease of the pre- and post- processing of the gas. Therefore the application of CNG technology to the gas fields along the North African and Middle East coasts for transportation of natural gas to the natural gas markets in Europe is seen to be very attractive.

For a given annual standard volume of gas transported by sea (i.e. measured in MMSCF), the number of ships used will be dependent upon the technology used, the distance covered and the necessary unloading time. For the Mediterranean Sea, the figures involved make CNG particularly attractive.

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.

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.

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.

[0005] In general, the pressure and temperature conditions of the gas are extremely important for the overall configuration of the transportation 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 CNG containers, usually referred to as pressure vessels, together with the associated filling, transportation and emptying systems.

[0006] 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 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.

[0007] 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. However, in the particular for case of marine transportation, for example in ships, both large and small, there is a significant advantage in lowering the mass of the vessels, since that allows the use of reduced-power engines, but while still maintaining the same speeds of transport. Further, reduced-weight pressure vessels allow an increased weight of gas to be transported while still maintaining adequate ship-buoyancy. It is therefore desirable to use lighter-weight or lower wall-thickness pressure vessels.

[0008] It is also known that the use of extremely high pressure levels requires the pressure vessels to be correspondingly stronger, whereupon their costs of 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.

[0009] It is also desirable that companies operating in the sector of marine or sea transportation of CNG should conduct research into improved methods of filling/offloading from the gas storage systems – methods that are suitable for the proposed transportation devices, which may increasingly carry a larger quantity of gas, so as to allow the off-loading or loading thereof to be performed rapidly, and without an increased occurrence of liquefaction of hydrates.

[0010] The systems most widely used for the transportation of CNG by sea 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 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).

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

[0011] 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.

Storage is performed inside the containers, which are suitably designed for this purpose, and they are connected to a specific piping system to allow loading/offloading.

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.

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 transported CNG, while still transferring it in a condition suitable for onward sale or distribution.

[0012] 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 delivery 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 thereof at the point of delivery.

[0013] It is known that the temperature of the expanding/offloading 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 offload, and this is to prevent or minimise liquefaction, which might otherwise occur in undesirable quantities.

[0014] 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 transport 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 handle since they have a smaller wall thickness, which again allows the transportation 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 transportation operations.

[0015] By reducing the storage/transportation 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 containers, and also to reduce the potential danger in the event of accidents. However, the additional conditioning of the gas by means of refrigeration results in greater both plant investment costs and energy consumption. In connection with CNG, in particular, the said conditioning operation results 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.

[0016] If the operating temperatures are lower than the ambient temperature, moreover it is essential to provide suitable heat insulation for the container system in order to limit heat exchange with the environment surrounding the containers. Moreover it is required to provide in some cases an additional cooling system, incorporated within the same container system, in the case of extreme atmospheric conditions or particularly long transportation times. The transportation of gas by sea over medium distances may after all last several days, and thus difficulties associated with bad weather or delivery problems need to be addressed.

[0017] 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.

[0018] 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.

[0019] 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.

[0020] 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 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 petrochemical industry, are various specific cooling and conditioning applications. However, they do not have the same aims as the present invention.

The following prior art publications relating to these processes have been identified and considered:

D1: US2006/0254287 (Greenberg et al.)
D2: US2002170297 (Quine et al.)
D3: US6212891 (Minta et al.)
D4: US6089028 (Bowen et al.)
D5: US6209350 (Kimble et al.)
D6: US6094937 (Paurola et al.)
D7: US4505127 (Pronovost et al.)
D8: WO2005005877 (Breivik et al.)
D9: WO0220352 (Bishop et al.)
D10: WO2009124372 (D Amorim et al.)
D11: US5803005 (Stenning et al.)
D12: US7155918 (Shivers)
D13: WO2008/109011 (White)

D1 describes a method for transporting and storing natural gas, which is also cooled and compressed, including also compression performed by means of cryogenic pumps, chilling and appropriate pressure storage inside storage containers; operating conditions at a temperature of about -80°C and a pressure of about 47 bar are envisaged.

D2 proposes the incorporation of heat exchangers for temperature adjustment during conditioning.

D3 and D4 suggest an improved, multiple-step, gradual, forced-chilling system also including energy recovery.

D5 describes a natural gas treatment system, also with liquefaction, including a plurality of heat exchangers and with energy recovery from the vapour flow.

D6 proposes the production of LNG with multiple cooling steps.

D7 describes a system for treating natural gas including "a cooler ... to reduce the volume of gas and to recondition the gas for rehydration".

D8 proposes a system for storing and transporting CNG by ship including containers arranged in closed spaces which are thermally insulated from the outside and provided with means suitable for cooling the said spaces.

D9 describes a system for storage and sea transportation of CNG suitable for operating with optimized compressibility and efficiency factors depending on the different operating temperatures and diameters and thicknesses of the containers. In particular temperatures of between 0 and -40°F (-17,8°C and -40°C) are envisaged.

D10 proposes an integrated method for the production and transportation of LNG or CNG, in particular for a floating station with a high production capacity, including the steps of collection, purification, separation, compression, cooling, removal of the condensable fraction and characterized by recovery of the energy accumulated during compression of the gas for use in the liquefaction step.

D11 describes a system for transportation of CNG by ship in a plurality of cylindrical containers arranged in compartments, including compression means, double high-pressure and low-pressure piping system, headers, valves, safety detectors and also a cryogenic unit located in a shore terminal for liquefaction.

Prior art closest to the invention

D12 proposes a system for treatment and transportation by ship of CNG in pressure vessels including, in sequence: a separator, a decontaminating unit for removing the impurities from the saturated gas; a dehydration unit for the production of dry and compressed gas; a device for cooling to an operating temperature of between -62°C and -84°C, resulting in a dual-phase vapour/liquid gas; at least one container inside the ship connected to the said cooling device and also to the separator so as to receive the dual-phase gas, the liquid and the condensate, keeping them at a pressure of between 800 and 1200 psi; suitable heat insulation of the containers; and a ship suitable for covering distances of between 500 and 2500 nautical miles, with use also of the compressed gas in the vapour state, as fuel for the ship.

D13 proposes a combined system for sea transportation of natural gas, also in the form of CNG, in a plurality of containers of the pressure vessel type which are connected in sequence at the bottom and also at the top so as to allow the treatment, filling, storage and unloading of the product under the required conditions. The system comprises operations for controlling the temperature, of the cooling and chilling type, including heat exchange with the seawater. Insulated containers, including an incorporated cooling system, are also envisaged.

[0021] From reviewing the prior art, it is known that a generic system for transportation of CNG or LNG or PLNG may be formed by:

- cylindrical containers, of the pressure vessel or pipe type, arranged parallel and alongside each other inside the hull; also organized in groups, and with the associated piping system including headers, valves, sensors and safety devices;
- devices for forced compression of the gas during filling, of the rotary turbomachine type;
- devices for reducing the temperature of the gas during filling with natural cooling, of the type using forced air supplied via fans;
- devices for reducing the temperature of the gas during filling with natural cooling, of the type using heat exchange with the seawater via gas-liquid exchangers;
- devices for reducing the temperature of the gas by means of forced chilling, using a conventional Carnot cycle refrigerating machine;
- devices for recompression of the gas during the intermediate and final steps of the process, of the rotary turbomachine type;

- a plurality of heat exchangers for transferring the heat from a secondary circuit to a primary circuit and vice versa;
- devices for purifying the gas and controlling and modifying its state, such as separators, a decontaminating unit for removal of the impurities, and a dehydration unit for the production of dry and compressed gas, with the incorporation also of heat exchangers and compressors;
- devices for controlling and modifying the phase state, such as separators, including a dehydrating unit for complete removal of the water content, with the incorporation also of heat exchangers and compressors;
- devices for removing the impurities, such as a decontaminating unit; and
- an electronic control system for automatically opening and closing the valves, of the DCS or PLC type.

Drawbacks

[0022] In general the known gas filling, treatment and land and sea transportation systems apply processes and devices which, considered individually, are widely known to the person skilled in the art in terms of their essential operating features. However, they become complex and original in nature when they are integrated and combined together in order to overcome the difficulties arising from specific applications. In the case of sea transportation of CNG, for example, a particularly delicate aspect is the control of the system variables when there is a variation in the atmospheric conditions, or in order to optimize investment costs and general transportation costs. In particular, the general configuration of the system can be improved in an integrated and balanced manner so as to optimize the financial outlay and operating costs by considering simultaneously the interaction between: structure and dimensions of the vessels, in particular if made of steel; filling and storage temperatures and pressures; natural cooling or forced chilling systems or also a combination of the two; energy consumption; power and tonnage of the ship used; piping systems; control systems; and safety systems.

Graphs showing the relationship between temperature, pressure and changes in state of a given gas are well known. Also known are systems for forced chilling of the natural gas by means of refrigerating machines so as to reduce the operating pressures and thus to use smaller containers or to transport a greater quantity of product.

The recent introduction of new pressure vessels with a diameter greater than 1 m, for example of 3 metres or more, has increased considerably the thicknesses and weights of the pressure vessels, thus requiring particularly powerful ships for their transportation. Consequently the general consumption levels, the polluting emissions and the corresponding investment in forced-chilling and liquefaction control means reduce the convenience of lowering excessively the temperature below to the ambient temperature since they have an impact on the overall energy performance and costs of the entire transportation system.

These drawbacks are particularly significant in the particular case where it is required to deliver the same quantity of product, but using transportation means with a lower weight, smaller size or lower operating pressures.

[0023] In general, in all the industrial processes, including those involving compressors, the known problem is that of the large quantity of energy used, said energy consumption levels being particularly high in the case of closed-cycle refrigerating machines. In D12, for example, the extremely low operating temperature exacerbates this problem.

[0024] A third problem encountered in the proposed low storage temperature systems, as described in D12 and D13, relates to the need to provide the containers with suitable heat insulation. This, in some cases, is together with an additional dedicated refrigerating system for the individual container or a combined system for conditioning the entire hold of the ship, as described in D8.

[0025] A fourth problem encountered and linked to the preceding problems is that of the large quantity of thermal energy which is dispersed by the refrigerating machines. This energy is not used advantageously in the temperature and pressure control system, whereby the prior art fails to increase the efficiency of their systems.

[0026] A fifth problem encountered is safety-related and concerns the need to manage, often with extreme precision, the temperature and pressure conditions of the gas inside the containers, so as to avoid the risk of vessel failures due, for example, to extreme variations in the atmospheric conditions, as can occur at sea, or during or as a result of a sea voyage from one location to another. The use of low operating temperatures, high pressures or containers with a small cross-sectional thicknesses, increases the risk and the difficulty of performing such control.

[0027] A sixth problem encountered relates to control of the change in state, in particular liquefaction, which condition is to be avoided in the case of CNG. The change in state is to be carefully monitored also so as not to risk delivering a quantity of CNG falling outside required delivery parameters.

[0028] Yet another problem relates to the complexity of the gas cooling plants and the corresponding increase in the energy expenditure. In D13, for example, it is envisaged to use liquid gas for mixing with the compressed gas to be stowed. This is done to lower the temperature of the latter. It is widely known that the production of liquid gas, however, requires the introduction of more complex (and therefore more costly) processing plants. And they require a considerable amount of energy. Moreover, the liquefaction plants have a high environmental impact.

A different solution also proposed in D13 presupposes a cooling of the gas by means of heat exchangers and expansion valves, all this again requiring high energy expenditure in order to perform the compression step upstream of the cooling step.

Again as described in D13, if the gas is not suitably dehydrated, the mixing of two hot and cold masses (displacement gas/cargo gas) could result in the formation of hydrates. Owing to the low operating temperatures, those hydrates can freeze and collect on the bottom of the tank. This may result in further problems. For example, if it collects and is not removed, it can hinder the incoming fluid flow when loading the tank.

[0029] A further problem relates to the entire system and concerns the limited efficiency, limited energy optimization and also limited integration of the processes which occur in the particular cases where it is required to deliver a given quantity of product using transportation means with a lower weight, smaller size or lower operating pressures.

[0030] Considering all of the above, it is reasonable to conclude that there exists the need for companies in the sector to find innovative solutions able to solve one or more of the aforementioned problems, or to improve upon the existing systems.

Summary of the invention

[0031] According to the present invention there is provided a system as defined in claim 1.

[0032] The present invention seeks to provide an integrated system for sea transportation of CNG, i.e. high-pressure compressed natural gas, which envisages the step of filling the containers, the filling step including multiple treatment steps for lowering the temperature, the steps being of the combined cooling and chilling type, with the aim to decrease the working pressure when carrying the same quantity of gas or to increase the gas density (and so the capacity) when maintaining the same working pressure.

For example, the invention discloses an integrated and improved system for conditioning a fluid in the gaseous state, for the sea transportation of CNG, in particular applied to the steps for performing filling and storage inside containers of the vertical pressure-vessel type, including multiple treatment steps for lowering the temperature, including a) air-jet cooling; b) seawater cooling using an exchanger for the seawater/gas, or seawater cooling; c) chilling with refrigerating cycle using an improved compressor/evaporator, or cryogenic cycle; where said treatment steps are combined with the aim to decrease the working pressure carrying the same quantity of gas or increase the gas density (so the capacity) maintaining the same working pressure; and where the gas stored and transported inside the said pressure vessels is thermally insulated from the exterior thereof.

According to claim 1 there is provided a system for conditioning a fluid in a gaseous state during filling of one or more pressure vessel, thus allowing control of the working conditions for storage of the fluid within the one or more pressure vessel, the system 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; and wherein the gas, once stored and transported inside the said one or more pressure vessel is thermally insulated from the surrounding environment or atmosphere by an arrangement in addition to the containment layer or layers of the one or more pressure vessel.

Preferably the system is integrated into a ship.

Preferably the fluid in a gaseous state is CNG – compressed natural gas.

Preferably the fluid in a gaseous state is CNG that is to be transported at sea.

Preferably steps a) to c) are carried out in sequence.

Preferably, the seawater cooling is carried out using a sea-water heat exchanger.

Preferably the working conditions for storage of the CNG, upon completion of the filling of the one or more pressure vessel are as follows: temperature of -30°C, +/- ΔT and pressure of 160 bar, +/- Δp; where ΔT and Δp can be chosen dependent upon the particular gas composition present, and where ΔT and Δp are preferably effectively zero in the case of pure methane. Alternatively, and for other compositions or gases, it might be that ΔT and Δp values might be from zero to up to the order of 2%, 5% or 10% in the case of pressures, or from zero to 1°, 2° or 4° in the case of temperatures.

Preferably 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.

Various predetermined ranges are possible, since each step may be required to adjust the temperature and pressure to a differing degree, or simply to maintain one of the temperature and pressure relatively constant while greatly changing the other.

Preferably treatment step a) is arranged to adjust the incoming fluid's temperature to a temperature of between 55°C and 65°C. Further, it can be arranged to adjust the incoming fluid's pressure to a pressure of between 150 and 170 bar, or to keep it substantially constant. More preferably it adjusts the incoming fluid's pressure and temperature to a temperature of between 57°C and 63°C and a pressure of between 157 and 163 bar. An optimum pressure to achieve, ready for transport, for chilled CNG, according to a preferred embodiment, is between 157 and 163 bar.

Preferably treatment step b) is arranged to adjust the incoming fluid's temperature to a temperature of between 10°C and 20°C. Further, it can be arranged to adjust the incoming fluid's pressure to a pressure of between 155 and 165 bar, or to keep it substantially constant. More preferably it adjusts the incoming fluid's pressure and temperature to a temperature of between 12°C and 18°C and a pressure of between 157 and 163 bar.

Preferably treatment step c) is arranged to adjust the incoming fluid's temperature to a temperature of between -35°C and -25°C. Further, it can be arranged to adjust the incoming fluid's pressure to a pressure of between 157 and 163 bar, or to keep it substantially constant. More preferably it adjusts the incoming fluid's pressure and temperature to a temperature of between -32°C and -28°C and a pressure of between 157 and 163 bar. An optimum temperature to achieve, ready for transport, for chilled CNG, according to a preferred embodiment, is between -32°C and -28°C.

Preferably in step c) the refrigerating fluid is 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%.

Preferably the fluid stored and transported in said working conditions inside the said at least one pressure vessel is thermally insulated from the surrounding environment by means of a heat-insulating material, and with additional conditioning provided by a refrigerating machine with associated coils inside which the refrigerating fluid flows; and where the said coils are arranged in contact with the structure which is more thermally conductive and close to the transported gas, so as to keep the said gas in the appropriate conditions for transfer.

Preferably the fluid stored and transported in the said operating conditions inside the said at least one pressure vessel is thermally insulated from the atmosphere by a system including a hermetically sealed compartment containing the at least one pressure vessel, the compartment being inerted with nitrogen.

Preferably the system comprises temperature lowering devices that comprise valves and sensors which are managed integrally by means of control logic units; and where the said control logic units are provided with dedicated processors and software for managing the entire conditioning system.

The present invention also provides a ship comprising a plurality of pressure vessels and a system as defined above for connecting thereto during filling of one or more of the pressure vessels. The system might alternatively be fitted to an off-ship structure.

The present invention also provides a method of filling a pressure vessel that utilises the above system.

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.

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;
- reliability and regularity;
- bathymetric characteristics water depth and movement characteristics; and
- ship operation: proximity and manoeuvring.

A typical platform comprises an infrastructure for collecting the gas which 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 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.

Solutions utilizing buoys can be categorized as follows:

- CALM buoy;
- STL system;
- SLS system; and
- 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.

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.

Objects

[0033] A first object is to increase the overall efficiency of the system, incorporating also processes, in cases where it is required to deliver a predetermined quantity of CNG, but using transportation means with a lower weight, smaller size or lower operating pressures.

[0034] A second object is to increase the precision of control of the system variables when there is a variation in the atmospheric conditions, in particular in order to avoid liquefaction and thus to deliver the exact quantity of CNG required.

[0035] A third object is to recover part of the thermal energy dispersed by the refrigerating machines in order to use it advantageously during conditioning of the gas before filling.

[0036] A fourth object is closely linked to the preceding objects and consists in providing an integrated method with also a reduction in the amount of external energy used in the process, and therefore to offer a cost-related benefit, a reduction in the polluting emissions in the atmosphere and a simplification of the entire process.

[0037] A fifth object is to increase safety by controlling more precisely the temperature and pressure conditions inside the containers so as to reduce the risk of failure of said containers in the event of extreme variations in the atmospheric conditions, e.g. by using an operating temperature lower than the ambient temperature.

[0038] Yet another object is to prevent the formation of hydrates inside the pressure vessels during loading (or offloading) by introducing for this purpose, where necessary, a dehydration unit.

[0039] These and other advantages, and the features of the present invention, will now be described in further detail, purely by way of example, with reference to the following detailed description of a preferred embodiment with the aid of the accompanying drawings.

Description of the drawings

Fig. 1a is a simplified block diagram relating to the conventional treatment of CNG during filling, at a temperature of 15°C and pressure of 250 bar.

Fig. 1b is a simplified block diagram relating to the inventive treatment of CNG during filling, at a temperature of -30°C and a pressure of 160 bar.

Fig. 2 is a diagram illustrating the preferred configuration of the novel filling and transportation method, including the combined cooling and chilling treatment, in relation to CNG.

Fig. 3 is a diagram illustrating the preferred configuration of the novel filling and transportation method, with the containers thermally insulated and also cooled.

Fig. 4 is a diagram illustrating an alternative configuration of the novel filling and transportation method, with containers inside compartments being conditioned using inert gas.

Practical embodiment of the invention

[0040] The illustrated embodiment of the present invention relates to a novel integrated system for sea transportation of CNG, i.e. high-pressure compressed natural gas, which envisages in particular the operation of filling the containers, including multiple treatment steps for lowering the temperature, of the combined cooling and chilling type, with the aim to decrease the working pressure carrying the same quantity of gas or increase the gas density (and thus the capacity) while maintaining generally the same working pressure.

[0041] It is known that sea transportation of compressed natural gas, or "CNG", is performed in most cases inside substantially cylindrical containers of varying diameter, preferably 1 m, and different lengths depending on the configuration of the hold. Said high-pressure containers are mainly of the pressure vessel or pipe type, arranged alongside each other in parallel and interconnected.

[0042] The proposed loading and storage method (Figs. 1b, 2, 3 and 4) envisages containers of the vessel type which can be inspected. They preferably are arranged vertically and also are preferably combined in modules, by way of a non-limiting example. It is preferred that 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, it is preferred that 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 can be connected in parallel to the main piping system, being referred to as "multilevel".

The said piping system is formed by three different and variable pressure lines which, in the case of a ship transporting about 200 MMScf, may be divided up into a "high" line, of between 250 bar and 140 bar, a "middle" line, of between 140 bar and 63 bar, and a "low" line, of between 63 and 30 bar.

Pressure vessels suitable for the transportation and delivery of CNG can be made of various materials, and using a variety of production 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 (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.
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.

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).
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;
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.
8. 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.

Prior applications describing preferred aspects of these vessels include PCT/EP2011/071793, PCT/EP2011/071797, PCT/EP2011/071805, PCT/EP2011/071794, PCT/EP2011/071789, PCT/EP2011/071799, PCT/EP2011/071788, PCT/EP2011/071786, PCT/EP2011/071810, PCT/EP2011/071809, PCT/EP2011/071808, PCT/EP2011/071800, PCT/EP2011/071811, PCT/EP2011/071812, PCT/EP2011/071815, PCT/EP2011/071813, PCT/EP2011/071814, PCT/EP2011/071807, PCT/EP2011/071801 and PCT/EP2011/071818, 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 differentiating the present invention over prior art arrangements.

[0043] The pressure and temperature conditions within a given pressure vessel, or of a fluid being loaded or offloaded thereto or therefrom, are closely interdependent and are also linked to the state of the fluid. In particular the fluid will typically be suitably conditioned by means of heat exchangers so as to release or acquire heat and also to prevent or minimise/reduce liquefaction.

[0044] The loading method proposed by the present invention is based essentially on the known principle of lowering of the temperature, and consequently the pressures, in order to allow transport of the same quantity of gas inside containers which are smaller or designed with dimensions for lower pressures and therefore are lighter. The method and system includes specially adapted natural cooling and forced-chilling systems, which are grouped together and ordered in a particular multilevel sequence to offer gradual lowering of the temperature. The innovative combination of treatment steps envisaged is intended to keep the gas in a condition advantageous for transportation as described above, and thus being stored in suitable conditions.

[0045] 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. Temperature decreasing is obtained by introducing a multilevel natural cooling system and a cryogenic refrigerant system during the loading phase. A suitable fluid, such as propane, periodically performs the transition from liquid to vapor passing through a compressor and a lamination valve, subtracting heat from the CNG.

[0046] Fig. 1a shows a simplified functional diagram of a conventional configuration, including devices for reducing the temperature of the gas during filing with natural cooling, of the type using forced air supplied via fans or of the type using heat exchange with the seawater via gas–liquid exchangers, also combined in sequence for greater efficiency;

[0047] Figure 1b shows a simplified and preferred functional diagram of the novel filling method for CNG where natural cooling is of the dual technology type and organized as two sequential stages in order to condition the gas gradually with minimum energy costs and minimum financial investment; this treatment is a preparatory step for subsequent treatment by means of an improved forced-chilling system.

[0048] The introduction of the chilling system allows one to consider a possibility of installing facilities that are necessary to cool both on board the ship (i.e. off-shore) and at the terminal/point of offload (usually onshore). In the second case, further cooling energy is needed in order to compensate the loss of refrigeration of gas along the pipeline that links the ship and the onshore network. This implies further associated costs.

[0049] Considering the process design of cooling, we can observe that in the reference case (Fig 1a), the natural gas is compressed from about 50 bar (or barg – bar gauge) to about 250 bar, and cooled down to 15°C. These are the storage conditions. In the case of the embodiment of the invention (see Fig 1b), however, the natural gas is compressed from 50 bar to 160 bar, it having been cooled down by a first stage of air cooling (21) to 60°C and by a second stage of sea water cooling (22) to 15°C, then it is refrigerated to -30°C by a third stage - a mixed refrigerant cycle (40).

[0050] With reference to Figure 2, the mixed refrigerant is compressed by the compressor (41) to about 20 bar, and is then condensed by the sea water exchanger (56), before being stored at about 25°C in the mixed refrigerant storage drum (43). It is then sub cooled to about 15°C by the sea water exchanger (57), and to about -30°C by the cryogenic exchanger (45). The sub cooled mixed refrigerant is then let down in the Joule-Thomson valve (44) 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 (45), 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 (42) before being sent back to the compressor (41).

[0051] As shown in Figure 2, treated natural gas is first of all compressed by passing through a compressor (11) in order to reach a desired storage pressure value, e.g. 160 bar. Consequently the temperature increases and a phase of cooling is needed. The cooling is operated by a system consisting in a fan (12) and a heat exchanger (55) using sea water as a working fluid. At this point gas enters into the chilling system (45) and undergoes the refrigeration cycle, which provides a further reduction of temperature, which is also helpful to overcome the loss of refrigeration due to transportation.

[0052] 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, all of which might already be stored on the ship. 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 carrying 600 MScf is 1.3 MW. With a nitrogen cycle and nitrogen circulation, it is 4.1 MW.

[0053] The power needed, above-mentioned, is refereed to an insulation system designed to lose no more than about 2°C per day.

[0054] The present innovation embodies various alternative methods for maintaining the cargo in a cold condition. One first possibility is to cool down the cargo to a lower temperature at first and then simply to let the cargo heat by a few degrees during the traveltime without it then exceeding preset limits. However, this would potentially lead to a problem if the ship or boat is delayed for any reason, such as due to it encountering or sailing around a storm, or due to industrial disputes; this problem, however, can be less incisive if designing thermo-insulating gas cylinders to be implemented as containment structures (a prior application describing this aspect is PCT/EP2011/071798, the whole contents of which are incorporated herein by way of reference). To keep the cargo cold whatever happens, two alternative choices are proposed: 1) circulate some liquid in coils inside the insulation (Fig. 3), 2) circulate directly the nitrogen inerting the module (Fig. 4).

[0055] In case of thermo-insulating solution, thermo-insulating materials (or thermo-insulating design features) are applied to the pressure vessels and possibly to the whole module or to the whole containment system.

[0056] In the first active solution (Fig. 3), a liquid hydrocarbon (for example C5+) at a temperature around -45°C is pumped (65) to a coil (63) contained inside the insulation surrounding the module; this liquid exchanges heat with the module (60), thus maintaining a cold temperature for the module, meanwhile the temperature of the liquid increases to a value of around -30°C. Afterwards the liquid, by passing through a refrigeration system (64), is returned to its initial reduced temperature, ready for recirculation.

[0057] In the second active solution (Fig. 4), the inerting nitrogen, at an initial temperature of around -50°C, blankets the pressure vessels contained in the module (60) and exchanges heat with them. The temperature of the nitrogen increases to a value of around -30°C. The nitrogen gas is then compressed and refrigerated in order to reach again its initial temperature. An analyzer (66) will check for possible methane leaks, and there will be a possibility to purge some nitrogen and to introduce nitrogen from storage to keep the nitrogen pure enough and to maintain a slight positive pressure in the storage module to avoid air entry.

[0058] As explained above, the chilling system represents an adequate solution for niche applications where limits on weight or space are likely to occur. Indeed, this solution, by permitting a transport to operate with lower pressures, allows the use of narrower wall thicknesses for the containment systems, and thus lower weights.

[0059] The entire procedure described above is preferred to be managed electronically by means of a DCS or PLC system using dedicated processors and software which are widely available.

[0060] An optimized filling method using the systems or developments described above is typically going to be designed to be in compliance with existing regulations governing high-pressure compressed gas devices, such as those of the ASME or API, and also other corresponding industrial standards.

Test data:

Although the cooling processes may be provided individual predetermined pressure and temperature targets, studies conducted only for a reference 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;
- Input Pressure= about 160 bar;
- Output Pressure= about 159.8 bar;

b) seawater cooling:

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

c) chilling:

- Input Temperature= about 15°C;
- Output Temperature= about -30°C;
- 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 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 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°C +/- ΔT, where ΔT does not exceed 5°C;

Step c) -30°C +/- ΔT, 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 +/- Δp, where Δp does not exceed 10 bar, and 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).

Key

(10) CNG compression process
(11) CNG compressor
(12) fan
(20) dual-stage cooling process
(21) air cooling
(22) sea-water cooling
(30) container filling
(40) improved chilling process
(41) refrigerating circuit compressor
(42) first drum
(43) second drum
(44) Lamination valve
(45) cryogenic exchanger
(55) seawater/gas heat exchanger
(56) first seawater/mixed refrigerant heat exchanger
(57) second seawater/mixed refrigerant heat exchanger
(60) module/hold
(61) heat insulation of the module
(63) coils for forced chilling of the module
(64) dedicated refrigerating machine for chilling the module
(65) refrigerating fluid circulation pump
(66) Analyzer methane leaks

Although the advantages of the present invention are described above in relation to ships and pressure vessels described to be carrying CNG, similar arrangements can likewise be used for transporting or loading other gases at high pressure.

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 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. commercial, industrial or residential.

The CNG will typically be carried at a pressure of 160 bar. However the present invention anticipates applications for use of the invention where the pressure is instead simply in excess of 60bar, or 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.

CNG can include various potential component parts in a variable mixture of ratios, some in their gas phase and others in a liquid phase, or a mix of both. Those component parts will typically comprise one or more of the following compounds: C_2H_6, C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, C_7H_{16}, C_8H_{18}, C9+ hydrocarbons, CO_2 and H_2S, plus potentially toluene, diesel and octane in a liquid state, and other impurities/species.

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 system for conditioning a fluid in a gaseous state during filling of one or more pressure vessel, thus allowing control of the working conditions for storage of the fluid within the one or more pressure vessel, the system 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; and wherein the gas, once stored and transported inside the said one or more pressure vessel is thermally insulated from the surrounding environment or atmosphere by an arrangement in addition to the containment layer or layers of the one or more pressure vessel.

2. The system of claim 1 integrated into a ship.

3. The system of claim 1 or claim 2, wherein the fluid in a gaseous state is CNG – compressed natural gas.

4. The system of any one of the preceding claims, wherein the fluid in a gaseous state is CNG that is to be transported at sea.

5. The system of any one of the preceding claims, wherein the steps a) to c) are carried out in sequence.

6. The system of any one of the preceding claims, the seawater cooling is carried out using a sea-water heat exchanger.

7. The system of any one of the preceding claims, wherein the working conditions for storage of the CNG, upon completion of the filling of the one or more pressure vessel are as follows: temperature of -30°C, +/- 4°C and pressure of 160 bar, +/- 10 %.

8. The system of any one of claims 1 to 6, wherein the working conditions for storage of the CNG, upon completion of the filling of the one or more pressure

vessel are as follows: temperature of -30°C, +/- 1°C and pressure of 160 bar, +/- 2%.

9. The system of any one of the preceding claims, 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.

10. The system of any one of the preceding claims, wherein treatment step a) is arranged to adjust the incoming fluid's temperature to a temperature of between 55°C and 65°C.

11. The system of any one of the preceding claims, wherein treatment step b) is arranged to adjust the incoming fluid's temperature to a temperature of between 10°C and 20°C.

12. The system of any one of the preceding claims, wherein treatment step c) is arranged to adjust the incoming fluid's temperature to a temperature of between -35°C and -25°C.

13. The system of any one of the preceding claims, wherein in step c) the refrigerating fluid is 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%.

14. The system of any one of the preceding claims, wherein the gas stored and transported in said working conditions inside the said at least one pressure vessel is thermally insulated from the surrounding environment by means of a heat-insulating material, and with additional conditioning provided by a refrigerating machine with associated coils inside which the refrigerating fluid flows; and where the said coils are arranged in contact with the structure which is more thermally conductive and close to the transported gas, so as to keep the said gas in the appropriate conditions for transfer.

15. The system of any one of the preceding claims, wherein the gas stored and transported in the said operating conditions inside the said at least one pressure

vessel is thermally insulated from the atmosphere by a system including a hermetically sealed compartment containing the at least one pressure vessel, the compartment being inerted with nitrogen.

16. The system of any one of the preceding claims, comprising temperature lowering devices that comprise valves and sensors which are managed integrally by means of control logic units; and where the said control logic units are provided with dedicated processors and software for managing the entire conditioning system.

17. A ship comprising a plurality of pressure vessels and a system according to any preceding claim for connecting thereto during filling of one or more of the pressure vessels.

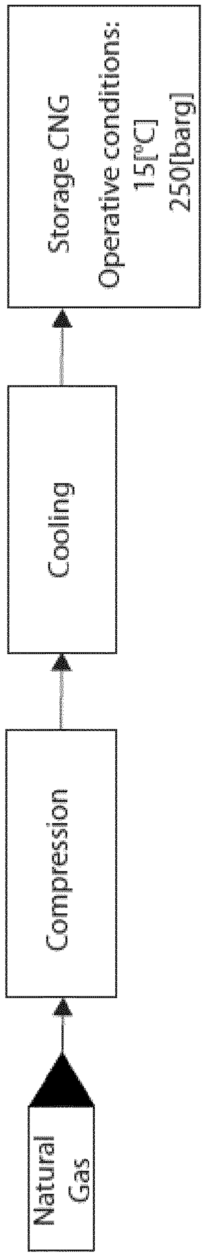
Natural Gas
Compression
Cooling
Storage CNG
Operative conditions:
15[°C]
250[barg]

Fig. 1a

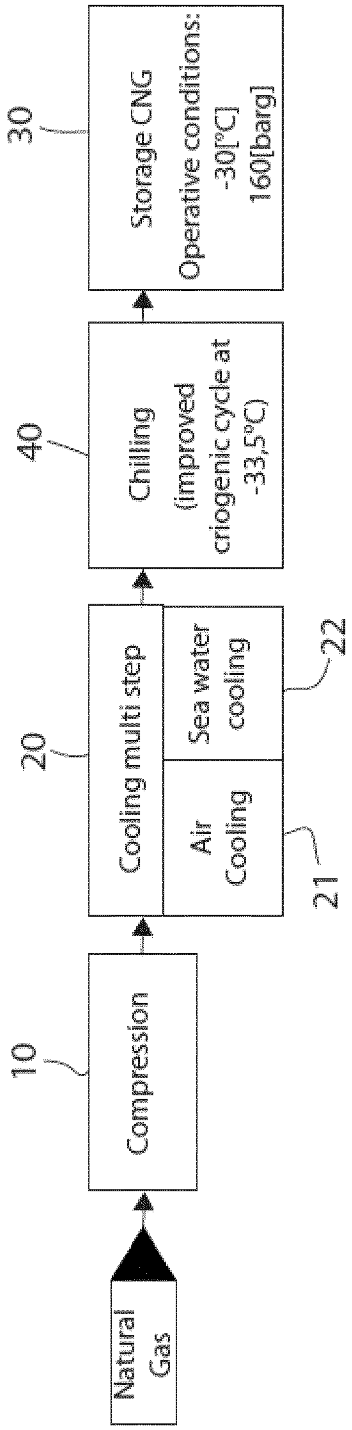
Natural Gas
10
Compression
20
Cooling multi step
Air Cooling
21
Sea water cooling
22
40
Chilling (improved criogenic cycle at -33,5°C)
30
Storage CNG
Operative conditions:
-30[°C]
160[barg]

Fig. 1b

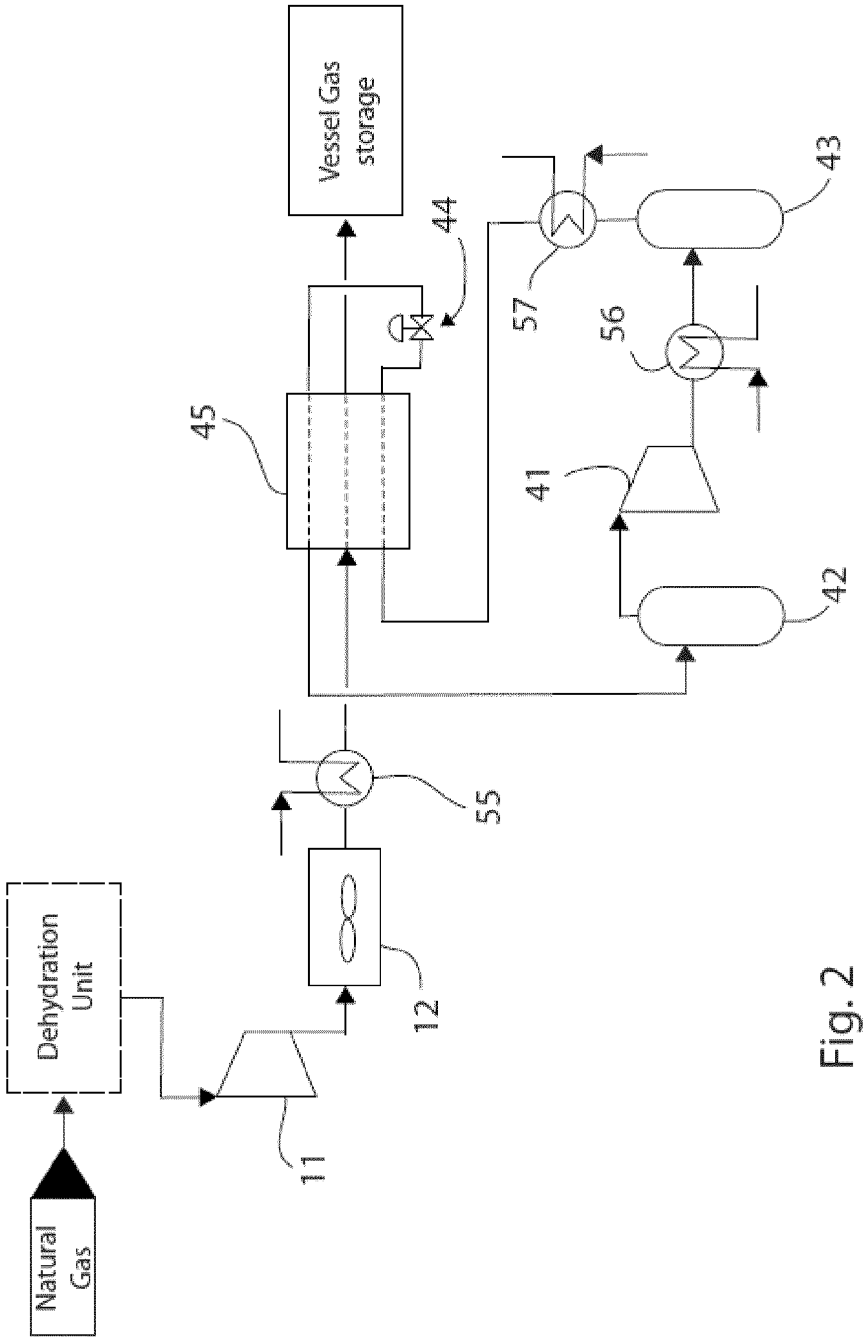
Vessel Gas storage
44
43
57
56
45
41
42
55
12
Dehydration Unit
11
Natural Gas

Fig. 2

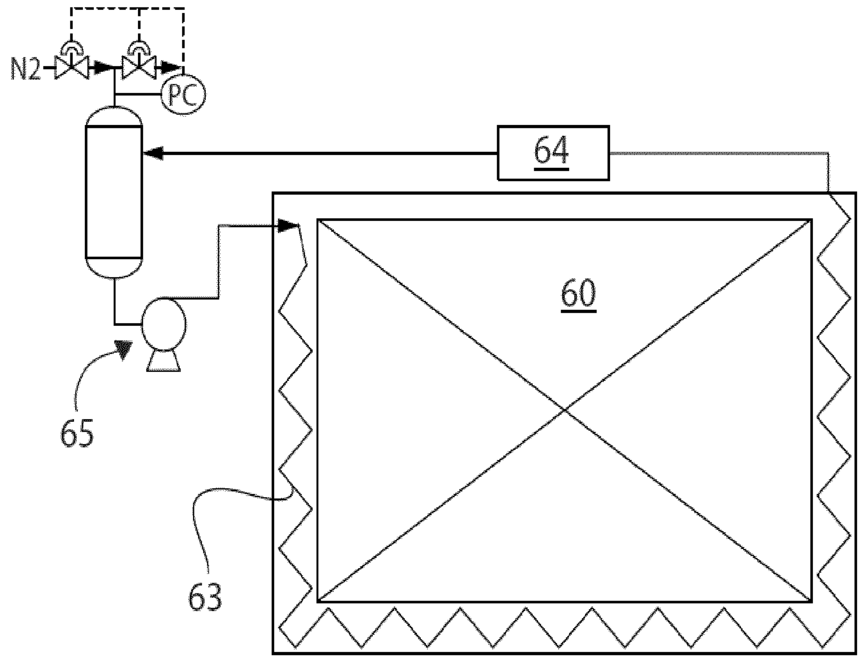

Fig. 3

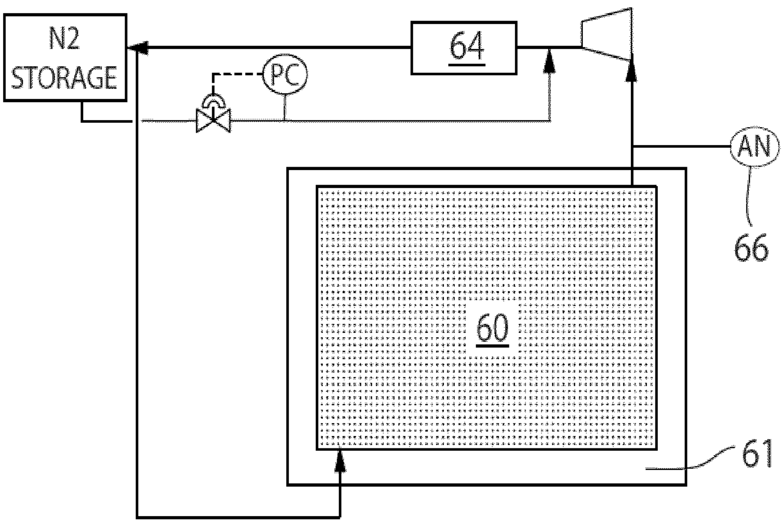

Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/074556

A. CLASSIFICATION OF SUBJECT MATTER
INV. F17C3/02 F17C6/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F17C

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/005877 A1 (CETECH IPR AS [NO]; BREIVIK KARE [NO]; RAVNDAL OLA [NO]; EIDE SVEIN IN) 20 January 2005 (2005-01-20) cited in the application page 7 the whole document -----	1-17
X	US 2006/254287 A1 (GREENBERG RALPH [US] ET AL) 16 November 2006 (2006-11-16) cited in the application claims 1,2 the whole document -----	1-17
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 October 2013	24/10/2013

Name and mailing address of the ISA/	Authorized officer
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1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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1

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Information on patent family members

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