(54) Title: SCAVENGING SYSTEM

Fig. 1

(57) Abstract: A vessel emptying system for emptying CNGs from a vessel used to transport CNG, the vessel being one of a plural -ity of cylindrical containers that are arranged vertically, with substantially parallel axes, wherein said system is arranged to expand

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the CNG through a turboexpander-compressor device (40, 50), the turboexpander-compressor device (40, 50) being adapted to use kinetic energy from the resulting rotation or movement of that turboexpander-compressor device (40, 50) in a secondary gas processing step of the system, publication
SCAVENGING SYSTEM

The present invention relates to a novel integrated scavenging system with energy recovery in the form of movement and heat, applied to the emptying of containers for the transport of compressed natural gas, in other words CNG, via an optimized device of the turboexpander-compressor type and heat exchangers.

Field of application

Combustible gas transported by sea, in the form of CNG (Compressed Natural Gas), is mainly formed of gaseous methane, but it also generally contains a liquid fraction. It is transported at a high pressure - the optimum conditions for transporting CNG correspond to about 250 bar at ambient temperature (e.g. 20°C), or else at a lower temperature, about -30°C, and a pressure of about 130 bar.

Compared with the transportation of liquefied low-pressure gas, or LNG, the advantages arising from the transportation of CNG are considerable, especially in terms of global investment, transportation times per unit end-product volume and unloading methods. In particular, CNG technology provides for the construction of simple unloading terminals, i.e. on- or off-shore platforms where the gas can be admitted under the pressure conditions suitable for sale, and not of complex regasification installations as required by LNG technology. Indeed, said regasification installations are very costly, potentially hazardous, impact on the environment and are not very suitable for sitting naturally into their environment - for convenience they would typically need to be located in costal regions, i.e. near off-shore transportation routes, such as around the European Mediterranean coast, and especially the Italian coast, and in such locations they would be particularly anthropizing - something that would cause difficulties with local planning authorities.

In addition, CNG technology is generally more efficient than LNG technologies since it entails both extremely small percentages of gas losses, and lower energy expenses, per unit of transported gas. These factors help to reduce the environmental impact compared to LNG processes, especially in terms of global greenhouse gas emissions throughout the process.

CNG technology is also of particular interest for the Mediterranean zone since it offers better global convenience than LNG processes in respect of the small to medium
distances travelled in that market - e.g. from the repositories on the North-African and Middle-East coasts to the European markets. For example, for a similar annual number of units of transported gas, as transported by sea, the number of ships committed to transporting the gas as CNG, compared to LNG, may ultimately be lower since loading/unloading times can be shorter. As a result, the number of ships required, and the technology to use, can be closely linked to the technology used, to the distance covered and to the necessary unloading times.

With CNG technology, due to the high operating pressures of the stored gas, and of the loading/unloading mechanisms, it has been necessary to introduce or develop new containers for storing the CNG, i.e. pressure vessels. Likewise, new transportation vehicles and loading and emptying systems have had to be introduced or developed for carrying, loading and emptying those vessels. The present invention relates in particular to the equipment used for the emptying or evacuation of the vessels. This part of the process is commonly referred to as scavenging, and it consists of a controlled emptying or evacuation of the natural gas from the vessels, where the vessels are typically arranged in arrays, with each vessel in an array being positioned close to its neighbouring vessel(s), i.e. usually side-by-side. Typically they will be emptied progressively, one by one, and potentially such that the natural gas is transferred in a form, and at a pressure, that is suitable for sale. In general, these end conditions correspond to a gaseous state with a pressure of about 95 bar.

The intermediate conditions for the gas in the CNG scavenging process will be variable, depending on the quantity of gas which remains inside the individual offloading vessel, the ambient temperature conditions, or even any particular requirements for the storage area, or for any intermediate transportation.

Since it is difficult and costly to provide equipment for maintaining high and medium pressures, at times it is convenient to store the gas, or to transport it over short distances at lower pressures, i.e. before then recompressing it again for distribution and sale.

In known arrangements, the gas in the container has typically been emptied substantially completely, via extraction or suction devices, generally involving pumps, turbines or compressors, i.e. to pressures at or close to, or even somewhat below, atmospheric pressures. This has been to maximise the gas capture from the vessels. It is also known that the same pumps etc can be used to recompress the gas at the
outflow thereof, or for pumping gas back into the vessels during the loading phase. However, it is now observed that a significant amount of time, money and energy is wasted by providing and using these pumps, turbines or compressors, particularly during the expansion phase (as the CNG expands out of the vessels). Further, a considerable amount of energy is consumed by them during their compression steps - in activating the mechanisms of the compression devices - there are un-utilised movements of the mechanisms or turbines.

From a mechanical point of view, the two movements - pumping to empty, or compression to fill, are very similar, and it would therefore be desirable, on the part of the companies which operate in the sector of CNG transportation, to provide a scavenging system which is improved over those prior art arrangements. One area being considered, therefore is the recovery of some of, or even the majority of, the energy lost in expansion phases, and advantageously also that which may be recovered during recompression phases.

Equally, it has been observed that the recompression of gas, from low pressure to medium pressure, brings about a temperature increase which is not required in the process and provides energy available in the form of heat. Additionally, it is observed that the reduction from high pressure to medium pressure, via expansion, may require the stream to be preheated so as to avoid liquefaction. Typically that is achieved by using an external heat supply. It would therefore also be desirable, on the part of the companies which operate in the sector of CNG transportation, to provide scavenging systems which allow some recovery of the generated heat and increasing the efficiency of the entire process, while still ultimately supplying the desired product under the correct end conditions.

**Prior art**

The systems which are mainly used for the transportation of CNG by sea provide for a plurality of cylindrical containers of varying diameter and length, predominantly having a diameter of 1 metre, which are placed in parallel sets. They can be made of steel or composite materials and are designed specifically so as to sustain increased pressures and so as to be introducible into the hull of ships designed for this purpose.

The process for emptying said containers, in other words scavenging, mainly involves an expansion phase of the gas from high pressure, normally around 250 bar at ambient
temperature, to a medium pressure, such as about 96 bar. This phase is in preparation for the transfer of the CNG under the conditions suitable for sale, i.e. about 95 bar.

The process is influenced by the temperature of the fluid, which cannot be reduced excessively since it is necessary to avoid or minimise liquefaction, and by the level of residual gas in the container.

In some cases, the pressure is deliberately reduced to much lower levels in an intermediate phase, for example 10 bar, so as to make operations to store the gas and transport it over short distances easier (less specialised equipment can be used for the storage and transportation of lower-pressure forms of the gas). The gas is then recompressed to the correct levels for delivery, i.e. 95 barg.

Special turboexpanders for handling compressed gas, which convert kinetic energy produced by the rotor into useful mechanical energy, are known. One particular type of turboexpander machine which recovers the kinetic energy is arranged to have the turbo expander activate a compressor that predominantly uses the same axle, or drive shaft, as the turboexpander. This type of device is commonly referred to as a turboexpander-compressor unit and work is obtained from the expansion of high-pressure gas in an isoentropic process, i.e. with constant entropy. As such, the stream of gas which leaves the turbine at the reduced pressure is at a lower temperature. For this reason, these turboexpander-compressor devices are widely used in industrial refrigeration processes for optimizing traditional refrigeration cycles.

Other types of turboexpander devices are also known. For example, some are used in installations for the production of energy from natural or geothermal gas and also in installations for the production of LNG, mainly for the liquefaction of gas and in the recovery of energy for various applications.

An intermediate device which controls the speed of the transmission shaft is sometimes applied between the turboexpander and the activated machine, for example the compressor.

The CNG scavenging process of the present invention as defined herein is new. The prior art in relation to CNG applications does not disclose applications of the type in which turboexpander-compressors are used for the recovery of motive force. Further they do not disclose integrations with exchangers in separate circuits for the recovery of
useful heat for maintaining the gaseous state, or applications in the context of expansion and compression on adjoining containers. Instead, known prior art relates mainly to LNG applications, and they are designed to optimize the efficiency of the installations for the production of such liquefied natural gas, or more broadly in refrigeration processes.

The following prior art has been identified:

D1: US5600969 (Low)
D2: US5755114 (Foglietta)
D3: US6023942 (Thomas et al.)
D4: US20060213223 (Wilding et al.)
D5: WO0157430 (Johnson et al.)
D6: US2010043488 (Mak et al.)
D7: US6138473 (Boyer-Vidal)
D8: US20080196384 (Ding)
D9: US6401486 (Lee et al.)
D10: US20090301131 (Bakker et al.)

D1 describes the use of a pressure reduction device of the turboexpander type, connected with a compressor which recompresses the part of the stream in the gaseous state after the separation and the stabilization so as to bring it to the correct pressure. This process is applied to an NGL (Natural Gas Liquids) production installation to produce small quantities of LNG (Liquid Natural Gas).

D2 describes an application of the turboexpander device in a process for the production of LNG (Liquefied Natural Gas). In particular, a plurality of exchangers for cooling and liquefying the main stream are fed with a proportion of gas, expanded using a turboexpander, which feeds the refrigeration circuit.

D3 describes a method for liquefying natural gas, mainly methane, which provides for a plurality of expansion, compression and refrigeration phases, wherein it is intended to couple a turboexpander with a compressor in an aligned manner.

D4 relates to a device and associated process for the liquefaction of natural gas, which provides for the gas to be split into two streams, a process stream and a cooling stream. In particular, the cooling stream is expanded and cooled using a turboexpander,
which also produces motive force useful for the activation of other devices used in the production cycle, for example a compressor.

D5 describes a system for the recovery of steam generated by a liquefied gas source, for example during the transfer of LNG from the containers for sea transport to the large storage tanks, using a system formed from a centrifugal-type compressor for the cryogenic production of refrigeration, with an associated heat exchanger, activated by the same rotary shaft of the turboexpander used to reduce the pressure.

D6 describes another method for the recovery of gas vapours in a process for the production of NGL using heat exchangers and a turboexpander coupled with a compressor, which increase the temperature of the gas and prevent it from freezing within the demethanizer.

D7 describes a station for the distribution of gas, in particular nitrogen, which station comprises a device which is intended for reducing and controlling the pressure and also for recovering energy and is formed substantially from a compressor, a heat exchanger and a turboexpander which includes a system for mechanically transmitting the movement to said compressor.

D8 describes a special device with two reciprocating compressors, arranged on the same axis, applied to a station for supplying compressed natural gas.

**Prior art closest to the invention**

D9 describes a system for the recovery of the volatile gas fraction in a process for the production of LNG, divided into multiple steps, said system comprising a plurality of devices suitable for the compression of gas and for the exchange of heat, some of which are dedicated to the working stream and others belong to the cooling circuits, wherein said compressors are interconnected by means of the same mechanism.

D10 describes a process for the production of LNG, comprising an integrated turboexpander-compressor unit dedicated to the main liquefaction phase and a separate unit formed by the compressor dedicated to the cooling circuit connected via the same activation mechanism to a different compressor dedicated to the aftertreatment of the main stream. Moreover, the system provides for different refrigerant circuits with heat exchangers for the treatment of the main stream, wherein
said refrigerant circuits may provide for mechanically interconnected compressors. The interconnected compressors are also activated by an external generator for start up or for possible integration.

Such LNG and similar applications are non-compatible with CNG applications for which the present invention is concerned due to the different pressures and temperatures involved. Nevertheless, it is reasonable to consider some of the teachings thereof to have a relevance to CNG applications. As such it is reasonable to suggest that CNG transportation and scavenging systems formed by the following basic elements are known, or within the scope of the knowledge of a skilled person:

- cylindrical containers, of the pressure vessel or pipe type, arranged in parallel and side-by-side inside the hull;
- a device, of the turboexpander type, suitable for reducing the pressure of the gas leaving an individual CNG container;
- a device, of the rotary turbomachine type, suitable for the compression of the gas for possible recompression before transfer and sale;
- a device, of the rotary turbomachine type, suitable for the removal of the useable gas remaining in the containers after the main emptying, at least to a point of atmospheric pressure;
- an electronic control system, of the Distributed Control Systems (DCS) or Programmable Logic Controller (PLC) type, for automatically opening and closing valves.

In addition, it is reasonable to consider an LNG gas treatment system formed by the following to be known, with particular reference to the liquefaction processes:

- a device, of the turboexpander type, suitable for reducing a pressure, coupled to a compressor via the same mechanism, wherein the movement imparted to the turbine by the gas in the expansion phase is used to activate the rotor of the compressor (said device is conventionally referred to as an expander-compressor unit);
- a device which joins together two compressors, even with different functions, via the same mechanism so as to recover kinetic energy from the first compressor to activate the second compressor, and vice versa;
- a plurality of heat exchangers for transferring the heat from a secondary circuit to a primary circuit, and vice versa.
Disadvantages in known CNG devices

Since applications known for scavenging compressed natural gas (CNG) at high pressure on ships are all relatively new, they are not optimised, above all in terms of global efficiency and emptying times. They also have some disadvantages. In particular it is known that a large amount of energy is passed through the turbine in the expansion phase of the compressed gas, and this energy is not captured for operating other mechanisms, for example compressors. Moreover, devices of the rotary compressor type are known for emptying residual gas from the containers, but mechanisms suitable for reducing the high energy consumptions involved within these processes are not known. Likewise, devices of the rotary compressor type are used for the recompression of the gas before transfer, but mechanisms suitable for reducing the high energy consumptions involved are again not known in the field of CNG.

A second problem which has been discovered concerns the organization of the typical CNG scavenging process. The process generally intends to carry out the primary emptying of the container with a relative expansion of the gas therein as it exits the container, so that the pressure of the exiting gas is reduced from a high pressure to a medium pressure. Further, this occurs in a phase which is separate from the phase of final emptying, which provides for an external action that completely or substantially completely empties the remaining gas content at a low pressure. That residual gas is subsequently recompressed so as to bring it to a medium pressure, and other required conditions suitable for transfer and sale.

A third problem which has been discovered is closely linked to the previous problems and concerns. In particular it concerns the fact that the multi-phase process provides for turbines and compressors, which are all activated by kinetic energy, but which are not interconnected, and therefore they move or operate independent of one another, i.e. both at different times and without any mechanical interaction.

A fourth problem which has been discovered concerns the presence of differentiated circuits for the treatment of the high pressure gas and of the low pressure gas, each operating with different fluid temperatures. It is known that the temperature of the fluid is closely linked to the pressure and that an excessive reduction of the former can result in liquefaction, and that is something which is to be avoided in the field of CNG, especially when operating close to the turboexpander (where liquefied content may cause damage to occur). For this purpose, provision is sometimes made of devices
suitable for increasing the temperature of the primary circuit so as to avoid or minimise liquefaction phenomena in the expansion phase by means of a pretreatment with heat exchangers, wherein said exchangers are fed with external energy (mechanisms which provide for the recovery of heat by sources within the CNG handling process are not known in the field of CNG handling).

It would be desirable to provide solutions for overcoming at least some of the problems mentioned above.

**Summary of the invention**

According to the present invention there is provided a vessel emptying system for emptying CNG (compressed natural gas) from a vessel used to transport CNG, the vessel being one of a plurality of cylindrical containers that are arranged vertically, with substantially parallel axes, wherein said system is arranged to expand the CNG through a turboexpander-compressor device, the turboexpander-compressor device being adapted to use kinetic energy from the resulting rotation or movement of that turboexpander-compressor device in a secondary gas processing step of the system. Such a system can also be referred to as a CNG scavenging system.

The CNG in the vessel will typically be high-pressure compressed natural gas, i.e. at a pressure of about 250 bar or higher.

Preferably the transport of the CNG is a shipped transport.

Preferably the kinetic energy is directed towards activating one or more compressors for increasing a pressure of a natural gas feed.

Preferably the one or more compressors increase the pressure to about 95 bar.

Preferably a turboexpander unit of the turboexpander-compressor device is mounted on a common axis with the one or more compressors.

Preferably the system comprises a motion generator for starting up the system or for inputting power to the turboexpander-compressor device in the event of a power shortage in the turboexpander-compressor device.
Preferably a turboexpander unit of the turboexpander-compressor device is mounted on a common axis with the motion generator.

Preferably the system comprises a speed regulation device between a turboexpander unit of the turboexpander-compressor device and a compressor of the system.

Preferably a stream of CNG from the vessel is directed into a primary circuit for processing through the turboexpander-compressor device, and a second stream, of residual gas extracted by force from elsewhere amongst the plurality of containers, is directed into a lower pressure secondary circuit for recompression by one or more compressors of the system.

Preferably the secondary circuit imparts heat to the primary circuit via one or more heat exchangers.

Preferably a first heat exchanger is provided for the pretreatment of a stream of CNG from the vessel.

Preferably the first heat exchanger is provided at or adjacent an inlet to a turboexpander unit of the turboexpander-compressor device.

Preferably the first heat exchanger is of an electrical type.

Preferably a stream of CNG is fed from the vessel at a pressure of about 250 bar, or at a pressure of no greater than 300 bar and no less than 90 bar.

Preferably a second stream of residual gas is extracted by force from the plurality of containers, and directed to a compressor of the system, the second stream being at a pressure of about 10 bar or at a pressure of no greater than 90 bar and no less than 5 bar.

Preferably the system is managed in an integrated manner via logic control units with dedicated processors and software.

Preferably the kinetic energy is used to drive one or more mechanisms of the system via a conventional mechanical transmission system.
Preferably the kinetic energy is used also to produce electrical energy.

It will be appreciated, therefore, that the present invention provides an integrated scavenging system for CNG (i.e. compressed natural gas - stored in a vessel at high pressure) for removing the CNG from the vessel, and also other containers, in particular of the pressure vessel or pipe type, with energy recovery being provided within the process in the form of recovered movements - kinetic energy - and heat. The process involves the use of a turboexpander-compressor type device, and optionally a plurality of heat exchangers. The preferred configuration of the invention provides for a primary circuit with the gas stream at high pressure, which is preheated in a heat exchanger and then expanded by a turboexpander. The expansion reduces the pressure of the gas but the system then recovers useful energy arising therefrom - the kinetic energy - for activating one or more preferably aligned compressors. Those compressors are then used both to bring the primary circuit to a pressure condition suitable for sale, e.g. 95 bar, and to also increase the pressure of the recovery circuit, which is before then at a low pressure, such as 10 bar. It may also be at a low temperature - sub zero °C. The increase can then allow that recovery circuit also to exit at a correct pressure value for sale. The secondary circuit, with the recompressed recovery gas, can also be used to provide heat to the primary circuit, or primary stream of CNG, via heat exchangers, so as to avoid or minimise liquefaction thereof during the decompression phase within the turboexpander, and to bring the exiting gas to required conditions.

Objects

Various and substantial objects are thereby achieved by the considerable creative contribution, which constitutes an instantaneous and considerable technical development.

A first object consists in the recovery of the large quantity of energy produced during the CNG scavenging by the turboexpander for the gas at high pressure, wherein said energy is used to activate other mechanisms, for example compressors.

A second object consists in the temporally contextual execution (i.e. the performance in parallel) of the primary emptying phase of the CNG container with a relative expansion of the gas so as to reduce the pressure from high pressure to medium pressure, and of the final emptying phase, which provides for external action to substantially completely empty the gas content from containers remaining at low pressure, and also in the
context of a recompression phase of gas at medium pressure. This process therefore accelerates the CNG scavenging operations considerably.

A third object is closely linked to the previous objects and consists in the provision of a multi-phase process, with the devices interconnected in terms of movement and therefore having both temporally and mechanically integrated and uniform activation. This integration offers a significant saving in the external energy needed to be used in the process, i.e. an economical and environmental advantage, such as by way of a reduction of the pollution emitted to the atmosphere, as well as an appreciable reduction of the total load emptying times for a transport vehicle. The system is also simple, and a substantial simplification compared to systems operating separate circuits for each extraction/compression/decompression phase.

A fourth object concerns the exploitation of the internal heat of the process supplied by the secondary circuit to increase the temperature of the primary fluid via heat exchangers. This is achieved with the heat exchangers.

A fifth object concerns the optimization of the entire CNG scavenging process, with an increase in the global efficiency.

The present invention will now be described in further detail, purely by way of example, with reference to the accompanying drawings, whereby these and other advantages will become increasingly apparent.

**Content of the drawings**

Fig. 1 shows a schematic arrangement illustrating a preferred configuration of the novel CNG scavenging process of the present invention.

Fig. 2 shows a schematic representation of an arrangement for interconnecting two modules of pressurised vessels on a ship; and

Fig. 3 shows a schematic representation of a module, or array, of pressurised vessels, each vessel forming a container for CNG.

**Carrying out the invention**
It is known that CNG (compressed natural gas) can be transported by sea, i.e. on ships and that transportation can be in substantially cylindrical pressure vessels or containers, and that those containers can be provided with a variety of diameters, although often they have a diameter of about 1 metre. Further, the vessels can have a variety of different lengths, depending on the configuration or depth of the ship’s hull, or the hold. For example, it is known to have lengths even as long as 10m or more, e.g. up to 30m. Such vessels may be, in effect, pipe-like. Further, said pressure vessels are usually formed from steel or composite-coated steel.

The present invention relates to a novel, integrated, CNG scavenging system for emptying such vessels or containers. The present invention offers energy recovery for recovering energy that exists in the form of movement and heat as a result of such scavenging.

The present invention also relates to an associated process for emptying, expanding and recompressing CNG.

The present invention can be implemented using any known arrangement of CNG pressure vessels, or with novel designs or configurations of CNG pressure vessels, or with known or new arrangements featuring a plurality of such pressure vessels that are interconnected by pipework. After all, the present invention relates to the handling of the scavenging (extraction) of the CNG from the vessels, rather than necessarily the design of the vessels themselves.

Preferred arrangements of pressure vessels, however, are shown in, for example, Figures 2 and 3.

As shown in those Figures, the pressure vessels 1 are of a generally cylindrical configuration and they are arranged alongside one another in parallel arrays, forming multiple arrays or modules 46 of pressure vessels 1.

Although the arrays or modules 46 may be stacked on top of one another, where space permits, in this embodiment, as shown, they are arranged side by side.
Within the modules 46, the individual pressure vessels 1 are shown to be in a vertical configuration. They are also interlinked with pipework 66, with CNG outlets being located towards the bottoms 7 of the vessels 10.

Valves 28 are provided for controlling the flow of the CNG from the vessels 1 or groups of vessels, whereby separate flow lines or flow streams are achievable from different vessels 1 or containers in the arrays, or from groups of vessels in the arrays, even from a common module 46. Figures 2 and 3 show valves 28 at the top. Valves may be instead, or may additionally be, at the bottom of each vessel. They may also be, or may instead be, in other areas of pipework.

The top 6 of each vessel is also provided with an inspection manhole to allow the inside of the vessels to be inspected.

Typically the outlets at the bottom 7 likewise act as inlets for loading of CNG into the vessels 1.

The preferred scavenging process proposed by the present invention is shown schematically in Fig. 1. It is for emptying said containers 1, and it provides for a primary circuit 10, wherein a stream of high-pressure gas is withdrawn from one or more individual containers. For convenience, the same security procedures and the same connection systems commonly used in CNG handling apparatus can be used.

As shown in Figure 1, that stream of high pressure CNG (taken from predominantly full pressure vessels, i.e. vessels with the CNG at a high pressure, e.g. at perhaps 95bar or higher) is initially pretreated by a heat exchanger 20 so as to be heated. That heat exchanger 20 can be an electrical heat exchanger, although it may take heat from elsewhere in the system and transfer it across to the incoming flowline 10.

The heated CNG is then expanded using a special device of the turboexpander-compressor type, formed from a turboexpander 40, which reduces the pressure of said gas and provides kinetic energy useful for the activation of one or more compressors 50 that is linked to and integrated with said turboexpander (or turbine) along a common axis, or even a common axle. Said compressors can then be mainly used to increase the pressure level of gas contained other system circuits, e.g. to bring it to a higher pressure, such as a correct pressure for delivery and sale. That gas feeds from the system through an outpipe 12, typically at a pressure of around 95bar. The system can
also be used to increase the temperature of gas within the system, and to drive pumps for emptying low pressure, or residual, gas, by force, from other containers in the module or other modules, i.e. vessels which have already been substantially emptied under the impetus of their own pressure.

Said residual gas is conducted through a secondary circuit 11 of the system, and it is at a lower pressure than the first stream 10. This occurs concurrently with the processing, or treatment phase, of the primary stream 10 from an adjoining container 1. As such, with the present invention, two streams of gas are concurrently processed.

The compression of the residual gas using the compressor driven by the expanding primary stream causes a heat to be given off by that residual gas. That heat can be used to heat the primary stream prior to expansion. This reduces the likelihood of liquefaction of the expanding primary stream.

The operations for the at least two different streams are therefore temporally, mechanically and thermodynamically contextual.

As indicated above, the secondary circuit 11 imparts a quantity of heat to the primary circuit 10, via a heat exchanger 20, and that can be, or should be made to be, sufficient to maintain the gaseous state of that primary stream as it expands. For example it would be desirable to increase the temperature of the primary stream from ambient temperature (the temperature of storage or transportation) by perhaps 10°C, thereby preventing or minimising the likelihood of the sudden decrease in temperature in the primary stream, caused by the subsequent expansion, from inducing excessive liquefaction.

A vertical separator 80 can possibly be placed downstream of the expansion device for dividing the outflow into the two phases, if partial liquefaction is nevertheless still going to be present in the stream. The composition of the CNG being delivered will determine this, and the separator can be selectively useable.

The gas stream thereby obtained at the outlet of the turboexpander can be arranged to be in a condition near to those under which it would be sold on, i.e. can be at a pressure value of about 95 bar. A compressor 50 placed downstream from the turboexpander 40 can help to maintain a constant pressure for the primary stream outlet. However, as is conventional with these arrangements, since the incoming CNG will itself have a varying
pressure (as the vessel unloads for example, it is generally the case that said the outlet pressure will be somewhat variable). This can also be influenced directly by the atmospheric conditions, i.e. not only by the residual quantity of gas present or remaining in the container/vessel 1 during the emptying/scavenging process.

The turboexpander-compressor unit is advantageously coupled to a further compressor 60 of the rotary type, which may be similar to the previous compressor 50. It can also be mounted on the same axis or axle of the turboexpander 40 and of the compressor 50, so as to further exploit the available kinetic energy from the turboexpander 40.

An external motor device 30, for example an electric motor can also be added for offering certainty for the operation of the turboexpander-compressor unit described above. It can be used if the system activated by the turboexpander 40, and the incoming CNG of the primary stream, does not have enough power/energy to maintain the operability of the system. It can also be helpful in a start-up phase, or during the emptying of the first container, to get the turboexpander spinning, whereby there will be less of a momentum change on the turboexpander 40. This can in particular be helpful when the recovered energy, supplied by the secondary circuit 11, originating from the preceding container, is absent. Said recovered energy, which is usually substantially in the form of heat for imparting to the primary circuit 10 by the exchanger 20, or even by other heat exchangers 22, e.g. at the outlet of the primary stream for regulating the outlet temperature of the gas for supply, will generally only make an automated contribution when the primary circuit 10 is withdrawing CNG from a CNG vessel 1, and while residual gas is being scavenged or pumped from a separate container or vessel 1 by means of the secondary circuit 11, or a pump thereof.

The secondary circuit 11 for handling the residual gas (at a lower pressure), as emptied by force from the container 1 - one which has already been partially emptied by the primary circuit 10, is advantageously recompressed two or more times, depending on the number of compressors 50, 60 installed on the modified turboexpander-compressor unit. Those compressors can be activated predominantly via the kinetic energy of the turboexpander 40.

Heat exchangers (20, 21, 22) are installed on the secondary circuit 11 for the advantageous use of recovered heat accumulated during the recompression phases of that secondary stream 11, such as for the primary circuit 10.
The modified turboexpander-compressor unit described above is for use in the field of CNG, and it makes it possible to recover a large quantity of kinetic energy which would otherwise be wasted.

The secondary circuit 11 is integrated alongside and parallel to the primary circuit 10, as described above. It makes it possible to recover a large quantity of thermal energy from within the process, which also would otherwise be wasted.

The present invention therefore is more efficient in terms of the amounts of lost energy involved, and in terms of both environmental impact and time lost (due to the concurrent processing of two streams of gas simultaneously.

The entire process described above can be managed electronically by a DCS or PLC system with readily available dedicated processors and software. These management systems can control the above-mentioned valves 28 as appropriate for ensuring appropriate flow from desired vessels 1, in addition to the flow within the scavenging system itself. Each valve may be separately controlled, or they may be controlled to operate, when needed, in unison.

The optimized scavenging process described above can conform to the Standards in force which regulate high-pressure compressed gas devices, for example ASME or API Standards, and the relevant industrial Standards.

Although this disclosure concentrates on CNG applications, the pressure vessels might equally be transporting or carrying a variety of other gases, such as raw gas straight from a bore well, including raw natural gas, e.g. when compressed - raw CNG or RCNG, or H₂, or C⁰₂ or processed natural gas (methane), or raw or part processed natural gas, e.g. with C⁰₂ allowances of up to 14% molar, H₂S allowances of up to 1,000 ppm, or H₂ and C⁰₂ gas impurities, or other impurities or corrosive species. The preferred use, however, is in relation 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.

CNG can include various potential component parts in a variable mixture of ratios, some in their gas phase and others in a liquid phase, or a mix of both. Those component parts will typically comprise one or more of the following compounds: C₂H₆, C₃H₈, C₄H₁₀,
C_5H_2, C_6H_4, C_7H_6, C_8H_8, C_9^+ 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.
### Key

<table>
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<td>(1)</td>
<td>pressure vessel</td>
</tr>
<tr>
<td>(6)</td>
<td>Top of vessel - an inspection manhole</td>
</tr>
<tr>
<td>(7)</td>
<td>Bottom of vessel - CNG inlet for loading and outlet for unloading/scavenging</td>
</tr>
<tr>
<td>(10)</td>
<td>primary circuit: high-pressure [HP] gas, about 250 barg/Tamb</td>
</tr>
<tr>
<td>(11)</td>
<td>secondary circuit or recovery circuit: low-pressure [LP] residual gas, about 10 barg</td>
</tr>
<tr>
<td>(12)</td>
<td>gas leaving the process under conditions suitable for sale, about 95 barg</td>
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<tr>
<td>(20)</td>
<td>heat exchanger [HE1], preferably of the gas/gas type</td>
</tr>
<tr>
<td>(21)</td>
<td>heat exchanger [HE2], preferably of the gas/gas type</td>
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<tr>
<td>(22)</td>
<td>heat exchanger [HE3], preferably of the gas/gas type</td>
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<tr>
<td>(28)</td>
<td>Valve</td>
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<tr>
<td>(30)</td>
<td>external generator, for example electric motor</td>
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<td>(40)</td>
<td>turboexpander [TE]</td>
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<tr>
<td>(46)</td>
<td>module</td>
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<tr>
<td>(50)</td>
<td>compressor [C1]</td>
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<tr>
<td>(60)</td>
<td>compressor [C2]</td>
</tr>
<tr>
<td>(66)</td>
<td>pipework</td>
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<tr>
<td>(70)</td>
<td>modified turboexpander-compressor unit</td>
</tr>
<tr>
<td>(80)</td>
<td>vertical separator (optional)</td>
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CLAIMS

1. A vessel emptying system for emptying CNGs from a vessel used to transport
CNG, the vessel being one of a plurality of cylindrical containers that are arranged
vertically, with substantially parallel axes, wherein said system is arranged to expand
the CNG through a turboexpander-compressor device (40, 50), the turboexpander-
compressor device (40, 50) being adapted to use kinetic energy from the resulting
rotation or movement of that turboexpander-compressor device (40, 50) in a secondary
gas processing step of the system.

2. The system of claim 1, wherein the transport of the CNG is a shipped transport.

3. The system of Claim 1 or claim 2, wherein the kinetic energy is directed towards
activating one or more compressors (50, 60) for increasing a pressure of a natural gas
feed.

4. The system of claim 3, wherein the one or more compressors increase the
pressure to about 95 bar.

5. The system according to claim 3 or claim 4, wherein a turboexpander unit (40) of
the turboexpander-compressor device is mounted on a common axis with the one or
more compressors.

6. The system according to any one of the preceding claims, comprising a motion
generator (30) for starting up the system or for inputting power to the turboexpander-
compressor device in the event of a power shortage in the turboexpander-compressor
device.

7. The system according to claim 6, wherein a turboexpander unit (40) of the
turboexpander-compressor device is mounted on a common axis with the motion
generator (30).

8. The system according to any one of the preceding claims, comprising a speed
regulation device between a turboexpander unit (40) of the turboexpander-compressor
device and a compressor (50) of the system.

9. The system of any one of the preceding claims, wherein a stream of CNG from a
vessel or a group of them is directed into a primary circuit (10) for processing through
the turboexpander-compressor device, and a second stream, of residual gas extracted
by force from elsewhere amongst the plurality of containers, is directed into a lower
pressure secondary circuit (11) for recompression by one or more compressors (50, 60)
of the system.

10. The system according to Claim 9, wherein the secondary circuit (11) imparts
heat to the primary circuit (10) via one or more heat exchangers (20, 21, 22).
11. The system according to any one of the preceding claims, wherein a first heat exchanger (20) is provided for the pretreatment of a stream of CNG from the vessel or a group of vessels.

12. The system of claim 11, wherein the first heat exchanger (20) is provided at or adjacent an inlet to a turboexpander unit of the turboexpander-compressor device.

13. The system of claim 11 or claim 12, wherein the first heat exchanger is of an electrical type.

14. The system of any one of the preceding claims, wherein a stream of CNG is fed from the vessel or a group of vessels at a pressure of about 250 bar, or at a pressure of no greater than 300 bar and no less than 90 bar.

15. The system of any one of the preceding claims, wherein a second stream of residual gas is extracted by force from the plurality of containers, and directed to a compressor of the system, the second stream being at a pressure of about 10 bar or at a pressure of no greater than 90 bar and no less than 5 bar.

16. The system of any one of the preceding claims, managed in an integrated manner via logic control units with dedicated processors and software.

17. The system of any one of the preceding claims, wherein the kinetic energy is used to drive one or more mechanisms of the system via a conventional mechanical transmission system.

18. The system of any one of the preceding claims, wherein the kinetic energy is used to produce electrical energy.

19. A CNG scavenging system substantially as hereinbefore described with reference to the accompanying drawing.

20. A ship fitted with a system according to any one of the preceding claims.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. F17C7/02 F17C9/00
ADD.

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

B. FIELDS SEARCHED

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

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

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  *A* document defining the general state of the art which is not considered to be of particular relevance
  *E* earlier application or patent but published on or after the international filing date
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*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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*A* document member of the same patent family

Date of the actual completion of the international search: 11 October 2012

Date of mailing of the international search report: 22/10/2012

Name and mailing address of the ISA:
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016

Authorized officer: Stangl, Gerhard
# International Search Report

**DOCUMENTS CONSIDERED TO BE RELEVANT**

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