

Installation for feeding a gas-consuming member with combustible gas and for liquefying said combustible gas

Technical field

5 The invention relates to the field of installations for treating a combustible gas, for example liquefied natural gas (LNG).

 The invention is more particularly directed towards an installation for, on the one hand, feeding a gas-consuming member with combustible gas and, on the other hand, liquefying said combustible gas.

10 Technological background

 Liquefied natural gas is stored in leaktight and heat-insulating tanks, in a liquid/vapour two-phase state of equilibrium, at cryogenic temperatures. The heat-insulating barriers of liquefied natural gas storage tanks are the site of heat flow which tends to heat the content of the tanks, which is reflected by evaporation of the liquefied
15 natural gas. The gas derived from natural evaporation is generally used to feed a gas-consuming member so as to upgrade it. Thus, on a methane tanker, for example, the evaporated gas is used to feed the powertrain for propelling the ship or the power generators supplying the electricity required for the functioning of the onboard equipment. However, although such practice makes it possible to upgrade the gas
20 derived from natural evaporation in the tanks, it does not make it possible to reduce its amount.

 Furthermore, when the combustible gas is formed from a gas mixture, the composition of the vapor phase derived from natural evaporation is different from that of the liquid phase and also has a tendency to vary over time. Specifically, the vapor
25 phase derived from natural evaporation naturally has a richer composition of the most volatile components, such as nitrogen for liquefied natural gas, than the liquid phase. Now, as a result of these variations in composition, the calorific power of the gas derived from natural evaporation like that of the liquefied gas remaining in the tank is variable over time when natural evaporation prevails. Now, feeding a consuming
30 member with a combustible gas whose calorific capacity undergoes substantial variations is liable to result in imperfect combustion of the gas and also in functioning defects and a variable yield for the gas-consuming member.

US-A-2010/170297 discloses a device for the reliquefaction of gas derived from natural evaporation in an LNG tank. This device includes a heat-exchange unit positioned above the LNG tank to condense the gas derived from natural evaporation by heat exchange with a secondary coolant liquid such as liquid nitrogen. The
5 installation envisaged for producing, cooling and liquefying nitrogen is energy-consuming.

JP 0960799 describes an LNG storage installation with an LNG vaporization circuit and a circuit for recondensing the gas derived from natural evaporation. Vaporization of the LNG in the vaporization circuit is produced by the heat supplied
10 by the heater 24.

Summary

An idea forming the basis of the invention is to propose an installation for feeding a gas-consuming member with combustible gas and for reliquefying said combustible gas, which does not have at least some of the drawbacks of the prior art.
15 Certain aspects of the invention start from the idea of using the liquid phase of the combustible gas as a coolant in a heat exchanger to cool and condense the gas derived from natural evaporation.

According to one embodiment, the invention provides an installation for feeding a gas-consuming member with combustible gas and for liquefying said
20 combustible gas; the installation including:

- a leaktight heat-insulating tank including an inner space intended to be filled with combustible gas in a liquid-vapor two-phase state of equilibrium;
- a heat exchanger placed in a higher position than the leaktight heat-insulating tank, the heat exchanger comprising a vaporization path and a
25 condensation path separated from each other in a leaktight manner by heat-exchange walls allowing heat to be transferred between a fluid contained in the condensation path and a fluid contained in the vaporization path, the vaporization path and the condensation path each including an inlet and an outlet,
- the inlet of the condensation path being connected to the leaktight and heat-
30 insulating tank by a vapor-collecting circuit including an admission emerging in an

upper portion of the inner space of the tank to withdraw a first stream of vapor-phase combustible gas in the inner space of the tank; the inlet of the condensation path is placed higher than the outlet of the condensation path,

- the outlet of the condensation path being connected to the inner space of
5 the tank to transfer by gravity a liquid fraction of the first stream of combustible gas in the inner space of the tank, the liquid fraction of the first stream of combustible gas being obtained by condensation in the condensation path,

- the inlet of the vaporization path being connected to the leaktight heat-insulating tank by a liquid inlet circuit, the liquid inlet circuit including an admission
10 emerging in a lower portion of the inner space of the tank to withdraw a second stream of liquid-phase combustible gas in the inner space of the tank and a circulation pump to transfer the second stream of liquid-phase combustible gas into the vaporization path,

- the outlet of the vaporization path being connected to a gas-consuming
15 member to transfer a vapor fraction of the second stream of combustible gas to the gas-consuming member, the vapor fraction of the second stream of combustible gas being obtained by vaporization in the vaporization path.

According to embodiments, such an installation may include one or more of the following characteristics.

20 According to one embodiment, the outlet of the vaporization path is placed lower than the inlet of the vaporization path. Thus, both the first stream of combustible gas in the condensation path and the second stream of combustible gas in the vaporization path perform a descending motion, which promotes the exploitation of gravity to maintain the circulation of these two streams. Moreover, this orientation of
25 the streams makes it possible to perform a co-current heat exchange between the liquid phase of the combustible gas used as coolant and the gas derived from natural evaporation to promote isothermal heat exchange by change of phase. Preferably, in this case, the vaporization path is configured for the second stream of combustible gas to flow in the form of falling liquid films.

30 According to one embodiment, the vaporization path of the heat exchanger includes a phase separation tank located at the bottom of the vaporization path, the

phase separation tank including a base wall and a side wall extending upward from the base wall, the vaporization path outlet emerging through the side wall of the phase separation tank at a position spaced above the base wall. By means of such a phase separation tank, it is easy to separate by gravity the vapor fraction derived from the
5 second stream of combustible gas from the fraction which has remained liquid.

According to one embodiment, a purge circuit emerges through the base wall of the phase separation tank to be able to evacuate a liquid phase from the phase separation tank by gravity. Thus, in the case where a non-vaporized fraction from the second stream remains, composed, for example, of the least volatile chemical species
10 of a mixture (heavy substances), removal of this liquid fraction is facilitated so as to avoid saturating or obstructing the vaporization path.

According to one embodiment, the vaporization path of the heat exchanger is placed under reduced pressure, i.e. at a pressure below the pressure prevailing in the vapor phase of the leaktight heat-insulating tank. It is thus possible to further force
15 the vaporization of the combustible gas in the vaporization path, by the cumulative effect of the supply of heat to the condensation path and of the reduced pressure in the vaporization path. Furthermore, given that the reduced pressure shifts the two-phase equilibrium temperature downward in the vaporization path, it is thus possible to increase the flow of heat transferred from the vapor phase in the condensation path
20 to the gas located in the vaporization path.

Preferably, in this case, the absolute pressure in the vaporization path is greater than 120 mbar absolute. In point of fact, it is preferable for the pressure inside the vaporization path to be greater than the pressure corresponding to the triple point of the methane phase diagram so as to avoid solidification of the natural gas inside
25 the vaporization path. The pressure in the vaporization path may especially be between 500 mbar absolute and 980 mbar absolute.

According to a corresponding embodiment, the installation also includes a vacuum pump or pressure reduction pump connected to the vaporization path to place the vaporization path of the heat exchanger at a pressure below the pressure
30 prevailing in the vapor phase of the leaktight heat-insulating tank.

According to embodiments, such a vacuum pump may be controlled as a function of a nominal flow rate or a nominal pressure. Such a nominal flow rate or pressure may be predetermined or generated by the gas-consuming member.

According to corresponding embodiments, the installation may have one or
5 more of the following characteristics.

- the installation includes a flow rate measuring sensor for sending a signal representative of the flow rate of the vapor stream sucked through the admission and delivered to the gas-consuming member and a control device for controlling the vacuum pump as a function of the signal representative of the flow rate of the
10 vapor stream and of a nominal flow rate generated by the gas-consuming member;
- the installation includes a pressure sensor for sending a signal representative of the pressure prevailing in the vaporization path and a control device for controlling the vacuum pump as a function of the signal representative of the pressure and
15 of a nominal pressure.

The connection between the outlet of the vaporization path and the gas-consuming member may be direct or indirect, depending on the requirements of the consuming member. According to one embodiment, the abovementioned vacuum pump is arranged between the outlet of the vaporization path and the gas-consuming
20 member. According to another embodiment, a compressor is arranged between the outlet of the vaporization path and the gas-consuming member to provide a vapor-phase gas stream at a pressure above the storage pressure in the tank.

According to one embodiment, the heat exchanger includes a leaktight heat-insulating envelope delimiting an inner space containing the condensation path, the
25 envelope being arranged above the leaktight heat-insulating tank and including a lower aperture communicating with the inner space of the leaktight heat-insulating tank and constituting the outlet of the condensation path.

Such a leaktight and heat-insulating envelope may be made in various ways, for example as an integral part of a top wall of the tank or alternatively in the form of
30 an assembly added to the top wall of the tank.

According to one embodiment, a top wall of the leaktight heat-insulating tank has an aperture connected to the lower aperture of the envelope, the envelope also including a fastening clip arranged around the lower aperture of the envelope, the fastening clip being attached to the top wall of the leaktight heat-insulating tank around
5 the envelope of the top wall.

Preferably, in this case, the heat exchanger also includes a collecting pipe extending from the lower aperture of the envelope to a position close to a top wall of the envelope and having a lower extremity emerging in the inner space of the tank and an upper extremity emerging in the inner space of the envelope, the collecting
10 pipe delimiting within the inner space of the envelope an inner space of the collecting pipe forming the vapor-collecting circuit and an outer space of the collecting pipe forming the condensation path of the heat exchanger.

By means of these characteristics, the heat exchanger and the vapor-collecting circuit may be made in a relatively sparingly bulky integrated form having a
15 relatively small surface for exchange with the external environment, which limits the heat flows liable to increase natural evaporation.

According to another embodiment, the installation includes a plurality of leaktight heat-insulating tanks including an inner space intended to be filled with the combustible gas in a liquid-vapor two-phase state of equilibrium, said vapor-collecting
20 circuit being a common collecting circuit connecting the inlet of the condensation path to each of said tanks to collect the gases derived from evaporation in each of the tanks. It is thus possible to exploit the heat exchanger jointly for a set of tanks.

According to a corresponding embodiment, the heat exchanger includes:

25 a plurality of tubes parallel to the collecting pipe arranged in the outer space of the collecting pipe around the collecting pipe, the parallel tubes constituting said heat-exchange walls of the heat exchanger,

an inlet distributor arranged in the inner space of the envelope, the inlet distributor extending to the periphery of the collecting pipe and having a base wall
30 through which emerges an upper extremity of each of the parallel tubes,

an inlet tube constituting the inlet of the vaporization path and extending through the envelope between the exterior of the envelope and the inlet distributor, an outlet case arranged in the outer space of the collecting pipe around the collecting pipe lower than the inlet chamber and having a top wall through which emerges a lower extremity of each of the parallel tubes, and

an outlet tube constituting the outlet of the vaporization path and extending through the envelope between the outlet case and the exterior of the envelope.

In order to maximize the yield of the heat exchanger, it is in fact desirable to make the thermal contact between the vaporization path and the condensation path over the greatest possible height of the outer envelope. Advantageously, the inlet distributor is arranged higher than the upper extremity of the collecting pipe. Thus, the parallel tubes can extend over virtually the same length as the collecting pipe.

According to one embodiment, the tubes parallel to the collecting pipe have heat-exchange vanes arranged on the outer surface of the tubes parallel to the collecting pipe.

According to one embodiment, the invention also provides a process for feeding a gas-consuming member with combustible gas and for liquefying said combustible gas by means of an abovementioned installation, including:

- introducing a first stream of vapor-phase combustible gas into the inlet of the condensation path from the upper portion of the inner space of the leaktight heat-insulating tank through the vapor-collecting circuit,

- transferring a second stream of liquid-phase combustible gas from the lower portion of the inner space of the tank to the inlet of the vaporization path by means of the circulation pump,

- exchanging heat between the first stream of combustible gas in the condensation path and the second stream of combustible gas in the vaporization path, so as to vaporize at least a fraction of the second stream of combustible gas, which is initially in the liquid phase, in the vaporization path while condensing at least a fraction of the first stream of combustible gas, which is initially in the vapor phase, in the condensation path,

- transferring by gravity the liquid fraction of the first stream of combustible gas from the outlet of the condensation path to the inner space of the tank, and

- transferring the vapor fraction of the second stream of combustible gas from
5 the outlet of the vaporization path to the gas-consuming member.

By means of the descending orientation of the condensation path, the first stream of combustible gas cooled by the heat exchange can flow by natural convection, i.e. by gravity, to the inner space of the tank, which promotes the production of suction in the vapor-collecting circuit, so as thus to maintain the first
10 stream without additional mechanical work.

Preferably, this process is performed so as to vaporize all or virtually all of the second stream of combustible gas in the vaporization path. Thus, by producing the vapor phase by forced vaporization of a liquid stream withdrawn from the lower portion of the tank, the content of the most volatile compounds is substantially equal
15 to that of the liquid phase of the gas stored in the tank. The concentration of the most volatile compounds of the vaporized gas stream is thus limited and substantially constant over time.

In addition, by means of such an installation, vaporization of the liquefied gas may be performed without the aid of an external heat source, as opposed to forced
20 vaporization installations using an exchange of heat with seawater, an intermediary liquid or combustion gases derived from motorization or specific burners.

The gas present in the upper portion of the inner space of the tank thus acts as a hot source for the stream to be vaporized. The installation also makes it possible simultaneously to produce a vapor stream and to cool and condense the vapor phase
25 derived from natural evaporation present in the gas headspace of the tank, so as to limit the natural evaporation.

According to one embodiment, the invention provides a ship comprising an abovementioned installation.

According to one embodiment, the invention also provides a process for
30 loading or emptying such a ship, in which combustible gas is conducted through

insulated pipelines from or to a floating or land-based storage installation to or from the ship's leaktight heat-insulating tank.

According to one embodiment, the invention also provides a system for transferring a combustible gas, the system comprising the abovementioned ship,
5 insulated pipelines arranged so as to connect the tank installed in the ship's hull to a floating or land-based storage installation, and a pump for driving a combustible gas stream through the insulated pipelines from or to the floating or land-based storage installation to or from the ship's leaktight heat-insulating tank.

Brief description of the figures

10 The invention will be better understood and further aims, details, features and advantages thereof will become more clearly apparent during the following description of a plurality of particular embodiments of the invention, given merely for illustration and without limitation, with reference to the attached drawings.

- **Figure 1** is a schematic illustration of an installation for feeding gas-
15 consuming members with combustible gas and for liquefying said combustible gas.

- **Figure 2** is a half-view in perspective and in longitudinal cross section of a heat exchanger that may be used in the installation of figure 1.

- **Figure 3** is a view in cross section of the heat exchanger of figure 2 along line III-III.

20 - **Figure 4** is an enlarged view of a heat-exchange tube of the heat exchanger of figure 2.

- **Figure 5** is a view similar to that of figure 1 showing another embodiment of the installation for feeding gas-consuming members with combustible gas and for liquefying said combustible gas.

25 - **Figure 6** is a cutaway schematic representation of a methane tanker's tank including such an installation and of a terminal for loading/emptying this tank.

Detailed description of embodiments

In the description and the claims, the term "combustible gas" has a generic nature and refers without preference to a gas constituted of a single pure substance or a gaseous mixture constituted of a plurality of components.

In figure 1, an installation 1 for, on the one hand, feeding one or more gas-consuming members with combustible gas and, on the other hand, liquefying combustible gas is illustrated. Such an installation 1 may be installed on land or on a floating structure. In the case of a floating structure, the installation 1 may be intended for a liquefaction or regasification barge or for a liquefied natural gas cargo ship, such as a methane tanker, or may more generally be intended for any ship equipped with a gas-consuming member.

The installation 1 illustrated in figure 1 includes a vapor outlet line 3 which can feed directly or indirectly various types of combustible gas-consuming members, not shown, namely, in particular, a burner, an electrical generator and/or an engine for propelling a ship.

Such a burner is integrated into a power production installation. The power production installation may especially comprise a steam production boiler. The steam may be intended to feed steam turbines for producing energy and/or to feed a heating network of the ship.

Such an electrical generator includes, for example, a diesel/natural gas mixed feed heat engine, for example of DFDE (dual-fuel diesel electric) technology. Such a heat engine can burn a mixture of diesel and natural gas or use one or the other of these two combustibles. The natural gas feeding such a heat engine must have a pressure of the order of a few bar to a few tens of bar, for example of the order of from about 6 to 8 bar absolute. For this, one or more compressors 4 may be provided on the vapor outlet line 3.

Such an engine for propelling the ship is, for example, a dual fuel two-stroke low-speed engine of "ME-GI" technology, developed by the company MAN. Such an engine uses natural gas as combustible and a small amount of pilot fuel which is injected before the injection of the natural gas in order for it to ignite. To feed such an engine, the natural gas must first be compressed at a high pressure of between 150

and 400 bar absolute, and more particularly between 250 and 300 bar absolute. For this, one or more compressors 4 may be provided on the vapor outlet line 3.

The installation 1 comprises a leaktight heat-insulating tank 2. According to one embodiment, the tank 2 is a membrane tank. By way of example, such membrane
5 tanks are described in patent applications WO 140/57221, FR 2 691 520 and FR 2 877 638. Such membrane tanks are intended to store combustible gas at pressures substantially equal to atmospheric pressure or slightly higher. According to other alternative embodiments, the tank 2 may also be a free-standing tank and may especially have a parallelepipedal, prismatic, spherical, cylindrical or multi-lobed
10 shape. Certain types of tank 2 allow gas storage at pressures substantially higher than atmospheric pressure.

The tank 2 comprises an inner space 7 intended to be filled with combustible gas. The combustible gas may especially be a liquefied natural gas (LNG), i.e. a gaseous mixture predominantly including methane and also one or more other
15 hydrocarbons, such as ethane, propane, n-butane, i-butane, n-pentane, i-pentane, neopentane, and nitrogen in small proportion. The combustible gas may also be ethane or a liquefied petroleum gas (LPG), i.e. a mixture of hydrocarbons derived from oil refinery essentially including propane and butane.

The combustible gas is stored in the inner space 7 of the tank 2 in a liquid-
20 vapour two-phase state of equilibrium. The gas is thus present in the vapour phase in the upper part 8 of the tank 2, and in the liquid phase in the lower part 9 of the tank 2. This stratification is obtained naturally due to the specific density of each phase. The localization of the liquid-vapor interface naturally depends on the level of filling of the tank 2. The equilibrium temperature of the liquefied natural gas corresponding to its
25 liquid-vapor two-phase state of equilibrium is about -162°C when it is stored at atmospheric pressure.

Above the top wall 5 of the tank 2 is shown a heat exchanger 10 which makes it possible in combination to reliquefy vapor-phase gas originating from natural evaporation in the upper part 8 of the tank 2 while at the same time forcibly vaporizing
30 liquid-phase gas taken from the lower part 9 of the tank 2.

For this, the heat exchanger 10 has a gastight outer envelope 11, which is preferably heat-insulating to limit the flow of heat entering from the environment, which is arranged above the top wall 5 of the tank 2 and whose inner space 12 is in communication with the upper part 8 of the tank 2 via at least two connections:

- 5 - a vapor-collecting circuit 13 which emerges at the top of the inner space 12 to bring combustible gas vapor to the top of the inner space 12,
- a condensate-return circuit 14 which emerges at the bottom of the inner space 12 to collect by gravity the combustible gas condensed in the inner space 12 and to bring it back into the tank 2.

10 In figure 1, the vapor-collecting circuit 13 and the condensate-return circuit 14 pass through the top wall 5 of the tank 2, but other arrangements are possible, especially for the condensate-return circuit 14, for example by passing through the side wall 6 in the upper portion 8 of the tank 2.

 As outlined at number 50, the vapor-collecting circuit 13 may include several
15 branches connected to several tanks to serve as a common collector connecting a set of tanks to the condensation path of the heat exchanger 10. Valves, not shown, may be provided on each branch to conserve the possibility of isolating the tanks together in this case.

 The condensate-return circuit 14 could be connected to several tanks in the
20 same way.

 To withdraw heat from the inner space 12, the heat exchanger 10 also has a vaporization circuit 15 which is arranged in the inner space 12, shown here in the form of a coil, but the shape of which may vary to a large extent. The vaporization circuit 15 is fed with liquid-phase combustible gas from the lower part 9 of the tank 2 via a
25 circulation pump 16 and an inlet tube 17 joining the inlet of the vaporization circuit 15 passing in a leaktight manner through the outer envelope 11. By taking the latent heat from the vapor-phase combustible gas which is in the inner space 12, the liquid-phase gas circulating in the vaporization circuit 15 becomes vaporized and the vapor phase thus formed flows to the outlet line 3 which is connected to the outlet of the
30 vaporization circuit 15 passing in a leaktight manner through the outer envelope 11. For this, the outlet of the vaporization circuit 15 is preferably located lower than the

inlet of the vaporization circuit 15. Thus, both the gas stream undergoing vaporization in the vaporization circuit 15 and the gas stream undergoing condensation in the inner space 12 have a descending motion, one under the effect of the circulation pump, the other solely under the effect of gravity and of the difference in density between the liquid and vapor phases.

Given that the liquid phase is much denser than the vapor phase, the consumption of vapor by condensation creates a permanent suction effect in the vapor-collecting circuit 13, as shown by the arrow 19. It is thus generally not necessary to provide a circulation pump in the vapor-collecting circuit 13.

In order to further force the vaporization of the liquid-phase combustible gas circulating in the vaporization circuit 15, it is possible to place said circuit under reduced pressure. To do this, as shown in figure 5, a vacuum pump 51 may be used, for example in place of the compressor 4. The vacuum pump 51 must be a cryogenic pump, i.e. a pump that is capable of withstanding cryogenic temperatures below -150°C. It must also be in compliance with the ATEX regulation, i.e. designed to avoid any risk of explosion. In addition, a pressure loss member, for example an expansion valve 45, is placed at the inlet of the vaporization circuit 15, preferably inside the outer envelope 11.

Figure 1 shows as a continuous line another possible arrangement of the vapor-collecting circuit, in the form of a collecting pipe 113 arranged concentrically in the condensate return circuit 14 from the upper part 8 of the tank 2 up to the top of the inner space 12. In this case, the introduction of vapor-phase gas takes place inside the collecting pipe 113 while the condensate return flows in the circular space around the collecting pipe 113 in the condensate return circuit 14. For the rest, the functioning is identical.

Although figure 1 illustrates a heat exchanger whose vaporization path is contained and bathed in the fluid of the condensation path, an inverted configuration is also possible, i.e. a condensation path contained and bathed in the fluid of the vaporization path. Other configurations are also possible, for example with a heat exchanger in which the two paths have substantially the same volume.

With reference to figures 2 to 4, another embodiment of the heat exchanger will now be described. The elements that are similar or identical to those of figure 1 bear the same numerical reference, increased by 100.

In figure 2, the outer envelope 111 has the general shape of a cylindrical
5 bottle of vertical axis, upturned with the neck downward. More precisely the main body delimiting the inner space 112 has a larger diameter than the condensate return tube 114.

The leaktight heat-insulating walls are formed here from two parallel layers of mutually spaced metal sheets, with a space placed under vacuum between the two.
10 Other forms of heat insulation might be used.

The condensate return tube 114 has diaphragms to absorb the thermal contraction during changes in temperature of the outer envelope 111, especially when it is placed in service. It is terminated at its lower extremity by a fastening clip 21 for fastening to the top wall of the tank 2.

15 The collecting pipe 213 is arranged concentrically in the condensate return tube 114 from the extremity of the condensate return tube 114 and penetrates into the inner space 112 over a large part of its height. The upper extremity of the collecting pipe 213 is open and emerges in the upper part of the inner space 112. To ensure the mechanical strength of the collecting pipe 213 in this position, fastening members may
20 be provided to attach the collecting pipe 213 to the outer envelope 111. For example, fastening lugs 22 are provided here at the upper extremity of the collecting pipe 213 and attached to the vaporization circuit 115, which is itself attached to the outer envelope 111.

The vaporization circuit 115 will now be described in greater detail. It
25 essentially includes:

- an inlet distributor 23 of circular or toric shape arranged at the top of the inner space 112,
- an outlet case 24 also of circular or toric shape arranged at the bottom of the inner space 112 around the collecting pipe 213, and

- a large number of vane tubes 25 extending parallel to the collecting pipe 213, preferably vertically, between the inlet distributor 23 and the outlet case 24.

The vane tubes 25 each have an upper extremity 27 emerging in the circular chamber 26 of the inlet distributor 23 through the base wall thereof and a lower extremity 28 emerging in the circular chamber 29 of the outlet case 24 through the covering wall thereof. They constitute the heat exchange walls of the heat exchanger 110, which together allow vaporization of the liquid phase flowing downward in the vane tubes 25 and condensation of the gas phase flowing downward in the inner space 112.

The vane tubes 25 are distributed throughout the inner space 112 all around the collecting pipe 213 as partially shown in figure 3, so as to maximize the area for exchange between the two streams and to homogenize the heat transfers.

Figure 4 shows two embodiments of the vane tubes 25. In the right-hand view, the tube body 30 is surrounded with vanes 31 in the form of discs extending transversely to the tube body 30 and distributed mutually spaced over the entire length of the tube body 30.

In the left-hand view, the tube body 30 is surrounded with vanes 32 in the form of rectangular or polygonal blades extending parallel to the tube body 30 over the entire length of the tube body 30 and distributed mutually spaced all around the tube body 30.

In one variant, not shown, the vanes are eliminated, which makes it possible to reduce the lateral bulk of each tube and thus to increase the number of tubes, to also obtain a high area for exchange.

The circular chamber 26 of the inlet distributor 23 has here a square cross section and extends along the line of the vane tubes 25, and thus at the periphery of the collecting pipe 213. Moreover, a conical wall is arranged at the center of the inlet distributor 23, with its top turned toward the upper extremity of the collecting pipe 213 to close off the center of the inlet distributor 23, and thus to force the vapor phase to flow laterally toward the top of the vane tubes 25 by exiting the collecting pipe 213.

An inlet tube 117 extends laterally from the circular chamber 26 to the exterior of the outer envelope 111. Leaktight welds or seals, not shown, are provided around the inlet tube 117 at the passage through the outer envelope 111 to conserve its leaktightness. The outlet tube 117 is connected to the circulation pump 16 via any
5 suitable pipe, preferably equipped with heat insulation.

The outlet case 24 has a hollow toric shape around the collecting pipe 213 and at a distance therefrom. Its base wall 33 is concave so as to form a phase separation tank for collecting by gravity the non-vaporized part of the liquid-phase gas stream injected from the inlet tube 117. A purge tube 34 emerging at the bottom of
10 the base wall 33 makes it possible to evacuate this liquid fraction, for example to reinject it into the tank 2. Moreover, an outlet tube 103 extends laterally from the circular chamber 29 to the exterior of the outer envelope 111. The outlet tube 103 emerges in the circular chamber 29 above the concave base wall 33, so as to avoid collecting the liquid phase. In practice, the level of filling of the base wall 33 must be
15 maintained relatively low to avoid over spilling of the liquid phase into the outlet tube 103. Leaktight welds or seals, not shown, are provided around the outlet tube 103 at the passage through the outer envelope 111 to conserve its leaktightness. The outlet tube 103 is connected to the combustible gas-consuming members, directly or via other gas-processing equipment, for example compressor, heater, etc.

20 In functioning, the fact that the vapor phase collected in the upper part 8 of the tank 2 is channelled at the top of the heat exchanger 110 via the collecting pipe 213 ensures, firstly, that the heat exchanger 110 works over substantially its entire height and, secondly, that a convection pumping/motion by condensation is ensured on the vapor phase. This vapor phase, which is relatively hot with respect to the liquid
25 phase that is in the lower part 9 of the tank 2, enters via the collecting pipe 213 and arrives at the top of the heat exchanger 110. It then comes into contact with the heat-exchange surfaces of the vaporization circuit, i.e. the tubes 25, becomes cooled, which creates a first suction effect by thermal contraction of the vapor, and then changes state by yielding its latent heat of vaporization to form droplets which then
30 descend by gravity to the concave base wall 35 of the outer envelope 111, which creates a second suction effect. It is thus possible to dispense with active pumping members to entrain the circulation of the vapor phase.

In the vaporization circuit 115, the architecture shown here with an inlet at the top and an outlet at the bottom uses a falling-film technique. The functioning to be obtained is that this film loses all the components that can vaporize during the interval between its entry into the chamber 26 and its arrival in the chamber 29, subject to the sparingly volatile substances that it is liable to contain and which will then arrive in liquid phase on the bottom wall 33.

A check valve 49 is preferably arranged on the purge tube 34 to close the purge tube 34 during the normal functioning of the installation and to open the purge tube 34 intermittently to remove the liquid fraction rich in heavy substances. Removal of the liquid fraction may be brought about either by injection of gas under pressure into the inlet tube 117, or by gravity under the sole effect of the hydrostatic pressure of the accumulated heavy substances. This purging operation may thus take place even when the installation is functioning.

Alternatively, a valve 149 is used on the purge tube 34 instead of the check valve 49, to be able to close the purge tube 34 if necessary and to open the purge tube 34 intermittently or continuously to remove the liquid fraction rich in heavy substances. Removal of the liquid fraction may be brought about by gravity when the valve is in the open position, under the sole effect of the hydrostatic pressure of the accumulated heavy substances. This purging operation may also take place when the installation is functioning.

Alternatively, a pump exterior to the tank, not shown, may be used to remove this remaining liquid fraction, intermittently or continuously. One of the advantages of this architecture is that the risk of saturation of the vaporization circuit 115 with the liquid phase is relatively limited: if the heat conveyed by the vapor is insufficient to ensure vaporization of the liquid, the remaining liquid phase can be removed as it arrives without interrupting the vaporization process. This would not be the case with a boiler container fed via the bottom and in which a liquid tail fraction is undergoing boiling.

As in figure 5, it is possible to further force vaporization of the liquid-phase combustible gas arriving in the vaporization circuit 115 by placing said circuit under reduced pressure. The purge device and its functioning will be modified in this case.

When the vaporization circuit 115 is placed under reduced pressure, a second valve 52 is added to the purge tube 34 upstream of the valve 149 so as to create a buffer volume 53 which may take the form of a tube or a reservoir. The functioning of the valves 52 and 149 is alternate: to begin with, the second valve 52 is opened to allow the buffer space 53 to fill up with the heavy substances. Next, the second valve 52 is closed before opening the valve 149 to empty the buffer volume by gravity, before closing the valve 149. The opening of the valves 52 and 149 may be brought about either by injecting gas or by electrical control such as for electrovalves.

- 10 The frequency of opening of the valves 52 and 149 is directly linked to the composition of the LNG: thus, the greater the fraction of heavy compounds included in the LNG, the more frequent the opening of the valves 52 and 149.

The architecture of the heat exchanger 110 makes it possible to perform parallel-current or co-current heat exchange. In theory, this form of heat exchange is less efficient than counter-current heat exchange. Specifically, in a two-fluid heat exchanger, the two fluids enter the exchanger with a given temperature difference between the two fluids. If the heat exchange takes place counter-currentwise, the outlet temperature of one of the fluids tends toward the inlet temperature of the other, and vice-versa. On the other hand, in a co-current exchanger, the two fluids tend toward a mixing temperature.

These considerations are not an obstacle to the correct functioning of the heat exchanger 110 which is used as an evaporator-condenser. Specifically, the portion of sensitive heat in the heat exchanges under consideration is minor, and the majority of the heat transfer is performed isothermally by phase change.

- 25 By way of illustration, if the vapor phase of the combustible gas enters at -100°C into the collecting pipe 213, the portion of sensible heat to make this vapor drop to -160°C is about 130 kJ/kg, whereas the latent heat required to condense it is 510 kJ/kg. Thus, the majority of the heat transfer is isothermal. This is likewise the case for the liquid phase in the vaporization circuit 115.

- 30 With reference to figure 6, a cutaway view of a methane tanker 70 equipped with an installation for feeding gas-consuming members with combustible gas and for

liquefying said combustible gas as described above is observed. Figure 6 shows a leaktight insulated tank 71 of generally prismatic form, mounted in the double hull 72 of the ship. The wall of the tank 71 includes a primary leaktight barrier intended to come into contact with the LNG contained in the tank, a secondary leaktight barrier arranged between the primary leaktight barrier and the double hull 72 of the ship, and two insulating barriers arranged, respectively, between the primary leaktight barrier and the secondary leaktight barrier, and between the secondary leaktight barrier and the double hull 72.

In a manner known per se, loading/unloading pipes 73 arranged on the upper deck of the ship may be connected by means of suitable connectors to a maritime or harbour terminal, in order to transfer a cargo of LNG from or to the tank 71.

Figure 6 shows an example of a maritime terminal including a loading and unloading station 75, an underwater pipeline 76, and a land-based installation 77. The loading and unloading station 75 is a fixed offshore installation including a mobile arm 74 and a tower 78 which supports the mobile arm 74. The mobile arm 74 carries a bundle of insulated hose pipes 79 which can be connected to the loading/unloading pipes 73. The orientable mobile arm 74 can be adapted to all sizes of tanker. A connecting pipeline, not shown, extends inside the tower 78. The loading and unloading station 75 allows the tanker 70 to be loaded or unloaded from or to a land-based installation 77. This installation includes liquefied gas storage tanks 80 and connecting pipelines 81 connected via the underwater pipeline 76 to the loading or unloading station 75. The underwater pipeline 76 allows the transfer of the liquefied gas between the loading or unloading station 75 and the land-based installation 77 over a great distance, for example 5 km, which allows the tanker 70 to remain at a great distance from the coast during the loading and unloading operations.

To generate the pressure required for the transfer of the liquefied gas, on-board pumps in the ship 70 are used, and/or pumps installed in the land-based installation 77, and/or pumps fitted to the loading and unloading station 75.

Although the invention has been described in connection with several specific embodiments, it is very obvious that it is in no way limited thereto and that it comprises all the technical equivalents of the means described and also combinations thereof, if the latter fall within the scope of the invention.

The use of the verb "to comprise" or "to include" and of its conjugated forms does not exclude the presence of elements or of steps other than those stated in a claim.

In the claims, any reference sign in parentheses should not be interpreted as
5 a limitation of the claim.

CLAIMS

1. An installation for feeding a gas-consuming member with combustible gas and for liquefying said combustible gas, the installation (1) including:

5 - a leaktight heat-insulating tank (2) including an inner space (7) intended to be filled with combustible gas in a liquid-vapor two-phase state of equilibrium;

- a heat exchanger (10, 110) placed in a higher position than the leaktight heat-insulating tank, the heat exchanger comprising a vaporization path (15, 115) and a condensation path (12, 112) separated from each other in a leaktight manner by
10 heat-exchange walls allowing heat to be transferred between a fluid contained in the condensation path and a fluid contained in the vaporization path, the vaporization path and the condensation path each including an inlet and an outlet,

- the inlet of the condensation path being connected to the leaktight and heat-insulating tank by a vapor-collecting circuit (13, 113, 213) including an admission
15 emerging in an upper portion (8) of the inner space of the tank to withdraw a first stream (19) of vapor-phase combustible gas in the inner space of the tank; the inlet of the condensation path is placed higher than the outlet of the condensation path,

- the outlet of the condensation path (14, 114) being connected to the inner space of the tank to transfer by gravity a liquid fraction of the first stream of
20 combustible gas in the inner space of the tank, the liquid fraction of the first stream of combustible gas being obtained by condensation in the condensation path,

- the inlet of the vaporization path (15, 115) being connected to the leaktight heat-insulating tank by a liquid inlet circuit (17, 117), the liquid inlet circuit including an admission emerging in a lower portion (9) of the inner space of the tank to withdraw
25 a second stream of liquid-phase combustible gas in the inner space of the tank and a circulation pump (16) to transfer the second stream of liquid-phase combustible gas into the vaporization path,

- a vacuum pump (51) connected to the vaporization path (15, 115) to place the vaporization path of the heat exchanger at a pressure below the pressure
30 prevailing in the vapor phase of the leaktight heat-insulating tank,

- the outlet of the vaporization path (3, 103) being connected to a gas-consuming member to transfer a vapor fraction of the second stream of combustible gas to the gas-consuming member, the vapor fraction of the second stream of combustible gas being obtained during functioning, by vaporization of the combustible gas in the vaporization path placed at a pressure below the pressure prevailing in the vapor phase of the leaktight heat-insulating tank.

2. The installation as claimed in claim 1, in which the vacuum pump (51) is arranged between the outlet of the vaporization path and the gas-consuming member.

10 3. The installation as claimed in claim 1, in which the outlet of the the vaporization path (15, 115) is placed lower than the inlet of the vaporization path.

4. The installation as claimed in claim 3, in which the vaporization path of the heat exchanger includes a phase separation tank (33) located at the bottom of the vaporization path, the phase separation tank including a base wall and a side wall extending upward from the base wall, the vaporization path outlet (103) emerging through the side wall of the phase separation tank at a position spaced above the base wall.

5. The installation as claimed in claim 4, also including a purge circuit (34) emerging through the base wall of the phase separation tank to be able to evacuate a liquid phase from the phase separation tank by gravity.

6. The installation as claimed in any one of claims 1 to 5, also including a compressor (4) arranged between the outlet of the vaporization path and the gas-consuming member.

7. The installation as claimed in any one of claims 1 to 6, in which the heat exchanger includes a leaktight heat-insulating envelope (11, 111) delimiting an inner space (12, 112) containing the condensation path, the envelope being arranged above the leaktight heat-insulating tank and including a lower aperture (14, 114) communicating with the inner space of the leaktight heat-insulating tank and constituting the outlet of the condensation path.

8. The installation as claimed in claim 7, in which a top wall (5) of the leaktight heat-insulating tank has an aperture connected to the lower aperture of the envelope, the envelope also including a fastening clip (21) arranged around the lower aperture of the envelope, the fastening clip being attached to the top wall of the
5 leaktight heat-insulating tank around the aperture of the top wall.

9. The installation as claimed in claim 8, in which the heat exchanger also includes a collecting pipe (113, 213) extending from the lower aperture of the envelope to a position close to a top wall of the envelope (11, 111) and having a lower extremity emerging in the inner space of the tank and an upper extremity emerging in
10 the inner space (12, 112) of the envelope, the collecting pipe delimiting within the inner space of the envelope an inner space of the collecting pipe forming the vapor-collecting circuit and an outer space of the collecting pipe forming the condensation path of the heat exchanger.

10. The installation as claimed in claim 9, in which the heat exchanger
15 includes:

a plurality of tubes (55) parallel to the collecting pipe arranged in the outer space of the collecting pipe around the collecting pipe, the parallel tubes constituting said heat-exchange walls of the heat exchanger,

an inlet distributor (23) arranged in the inner space of the envelope, the inlet
20 distributor extending to the periphery of the collecting pipe and having a base wall through which emerges an upper extremity of each of the parallel tubes,

an inlet tube (117) constituting the inlet of the vaporization path and extending through the envelope between the exterior of the envelope and the inlet distributor,

25 an outlet case (24) arranged in the outer space of the collecting pipe around the collecting pipe lower than the inlet chamber and having a top wall through which emerges a lower extremity of each of the parallel tubes, and

an outlet tube (103) constituting the outlet of the vaporization path and extending through the envelope between the outlet case and the exterior of the
30 envelope.

11. The installation as claimed in claim 10, in which the inlet distributor (23) is arranged higher than the upper extremity of the collecting pipe (213).

12. The installation as claimed in claim 11, in which the tubes (25) parallel to the collecting pipe have heat-exchange vanes (31, 32) arranged on the
5 outer surface of the tubes parallel to the collecting pipe (213).

13. The installation as claimed in any one of claims 1 to 12, also including a plurality of leaktight heat-insulating tanks including an inner space intended to be filled with the combustible gas in a liquid-vapor two-phase state of equilibrium, said vapor-collecting circuit (13) being a common collecting circuit
10 connecting the inlet of the condensation path to each of said tanks to collect the gases derived from evaporation in each of the tanks.

14. A process for feeding a gas-consuming member with combustible gas and for liquefying said combustible gas by means of an installation as claimed in any one of claims 1 to 12, including:

15 - introducing a first stream of vapor-phase combustible gas (19) into the inlet of the condensation path (12, 112) from the upper portion (8) of the inner space of the leaktight heat-insulating tank through the vapor-collecting circuit,

- transferring a second stream of liquid-phase combustible gas from the lower portion of the inner space of the tank to the inlet of the vaporization path (15,
20 115) by means of the circulation pump (16),

- placing the vaporization path of the heat exchanger at a pressure below the pressure prevailing in the vapor phase of the leaktight heat-insulating tank,

- exchanging heat between the first stream of combustible gas in the condensation path and the second stream of combustible gas in the vaporization path,
25 so as to vaporize at least a fraction of the second stream of combustible gas in the vaporization path placed at a pressure below the pressure prevailing in the vapor phase of the leaktight heat-insulating tank while condensing at least a fraction of the first stream of combustible gas in the condensation path,

- transferring by gravity the liquid fraction of the first stream of combustible gas from the outlet of the condensation path (14, 114) to the inner space of the tank, and

- transferring the vapor fraction of the second stream of combustible gas from the outlet of the vaporization path to the gas-consuming member.

15. A ship (70) including an installation (1) as claimed in any one of claims 1 to 12.

16. A process for loading or emptying a ship (70) as claimed in claim 15, in which combustible gas is conveyed through insulated pipelines (73, 79, 76, 81) from or to a floating or land-based storage installation (77) to or from the ship's leaktight heat-insulated tank (71).

17. A system for transferring a combustible gas, the system including a ship (70) as claimed in claim 15, insulated pipelines (73, 79, 76, 81) arranged so as to connect the tank (71) installed in the ship's hull to a floating or land-based storage installation (77), and a pump for entraining combustible gas through the insulated pipelines from or to the floating or land-based storage installation to or from the ship's leaktight heat-insulated tank (71).