SYSTEM AND METHOD FOR VAPORIZING A CRYOGENIC GAS-LIQUID MIXTURE FROM AN INTER BARRIER SPACE OF A CRYOGENIC STORAGE TANK

The present invention relates to a system for vaporizing a cryogenic gas-liquid mixture.

More particularly, the present invention is related to a system for vaporizing a cryogenic gas-liquid mixture withdrawn from the inter barrier space of a cryogenic storage tank.

The invention also relates to a method for operating a system for vaporizing a cryogenic gas-liquid mixture according to the invention, and to a liquefied gas carrier using such a system.

Background of the invention

Gases, for example natural gas, can be stored and transported by sea-going vessels in liquid state as liquefied gases or liquefied natural gas (LNG) if the transported gas is natural gas, a few millibars above atmospheric pressure, at cryogenic temperatures colder than – 150 °C, typically -161 °C, inside insulated cryogenic tanks.

Typically, insulated cryogenic tanks for liquefied natural gas are full containment type.

A first thin barrier of a metallic membrane provides liquid tightness between the liquefied natural gas and a first layer of a porous insulation material.

A second thin barrier of a metallic membrane is disposed between the first layer of a porous insulation material and a second layer of a porous insulation material.

The second layer of a porous insulation material is then supported by the inner hull of a sea-going vessel.

In case of rupture or leakage of the first thin barrier of metallic membrane, LNG will accumulate in the space between the first barrier of metallic membrane and the second barrier of metallic membrane. Said space is called inter barrier space (IBS).

The second barrier of metallic membrane will then provide liquid tightness and avoid the cryogenic liquid contacting the inner hull of the vessel, which could result in catastrophic failure of the vessel.

In the case of accumulation on LNG in the IBS, during the unloading of the storage tank, the liquid level inside the tank can decrease faster than the level of liquid accumulated inside the IBS, thus resulting in a pressure exerted from the load of the liquid onto the first barrier from the IBS side toward the inside of the tank. This pressure could then damage the first barrier and the overall integrity of the containment system.

To avoid this, dip tubes are disposed inside the IBS to drain LNG from the IBS. The dip tubes are arranged such that all liquid can be removed from the IBS.

LNG is withdrawn from the IBS through the drain tubes by gas lift.

A depressurization, that is an overall decrease of pressure, is created by the suction of a compressor connected to the dip tubes and because of the simultaneous depressurization of the space comprised between the suction of the compressor and the IBS, a part of LNG accumulated in the IBS will evaporate and rise in the tubes, lifting any remaining liquid with it in the form of a cryogenic gas-liquid mixture, which is in this case a mixture of LNG with evaporated LNG.

Then the liquid part of the cryogenic gas-liquid mixture withdrawn from the IBS must be vaporized before being disposed by incineration with the vessel gas combustion unit.

Vaporization is done by using the onboard forcing vaporizer, a shell and tube heat exchanger in which the liquid part of the cryogenic gas-liquid mixture, that is the LNG from the IBS, is vaporized by indirect heat exchange with steam while the gaseous part of the cryogenic gas-liquid mixture is superheated, resulting in a vaporized cryogenic gas-liquid mixture. However, as this forcing vaporizer is sized for much higher flow rates than the ones occurring during IBS draining, the temperature of the vaporized cryogenic gas-liquid mixture at the outlet of the vaporizer is much too high and can damage the impeller of the centrifugal compressor, as said impeller being typically made of aluminum.

Thus, the vaporized cryogenic gas-liquid mixture must be cooled down. Typically, this is done with cold natural gas (NG) received from an onshore terminal. This implies that the ship must be moored and connected to an onshore LNG terminal to drain the inter barrier space (IBS), making it difficult, if not impossible, to drain the IBS when the ship is at sea.

It is thus an object of the present invention to provide an improved system for vaporizing a cryogenic gas-liquid mixture which avoids the above disadvantages.

Summary of the invention

The object is solved by a system for vaporizing a cryogenic gas-liquid mixture according to claim 1, a method for vaporizing a cryogenic gas-liquid mixture according to claim 8 and a liquefied gas carrier comprising a system for vaporizing a cryogenic gas-liquid mixture according to claim 13.

The dependent claims refer to preferred embodiments of the invention.

Thus, the invention provides a system for vaporizing a cryogenic gas-liquid mixture, comprising

- A cryogenic gas-liquid mixture supply line for withdrawing cryogenic gas-liquid mixture from an inter barrier space of a cryogenic storage tank;
- A vaporizer for vaporizing the cryogenic gas-liquid mixture, the vaporizer being downstream the cryogenic gas-liquid mixture supply line;
- Instead of cooling down the vaporized cryogenic gas-liquid mixture with cold gas from an onshore terminal as described before, the invention advantageously uses cryogenic liquid from the ship to mix the cryogenic liquid with the vaporized cryogenic gas-liquid mixture, said cryogenic liquid being supplied from the ship itself via a cryogenic liquid supply line, the cryogenic liquid being supplied via the cryogenic supply line being stored onboard inside the cryogenic storage tank;

- The mixing of the vaporized cryogenic gas-liquid mixture and cryogenic liquid is performed by first spraying means for spraying the cryogenic liquid from the cryogenic liquid supply line into the vaporized cryogenic gas-liquid mixture. Hence, a direct heat exchange between the two fluids takes place, and the cryogenic liquid vaporizes within the vaporized cryogenic gas-liquid mixture, reducing the overall temperature of the resulting cold mixture to temperature levels suitable for the compressor, i.e. temperature levels below – 50°C;
- A mist separator is provided for separating off droplets of the cryogenic liquid from the cold mixture in case of an incomplete vaporization of the cryogenic liquid within the cold mixture, the mist separator being located downstream the spraying means and upstream the compressor, to catch any remaining droplets so that they cannot reach the compressor;
- A compressor located downstream a gas outlet of the mist separator, the aspiration of the compressor creating a depressurization within the system for vaporizing the cryogenic gas-liquid mixture.

Thus, no connection to an onshore terminal is required.

To improve the accuracy of the system, a temperature control valve can be located on the cryogenic liquid supply line to control the temperature at the compressor inlet by adjusting the flow of cryogenic liquid sprayed into the vaporized cryogenic gas-liquid mixture.

When the quantity of cryogenic gas-liquid mixture withdrawn from the inter-barrier space (IBS) is sufficient, i.e. exceeds a certain value, it is also possible to reduce the temperature of the vaporized cryogenic gas-liquid mixture by by-passing the vaporizer with a part of the cryogenic gas-liquid mixture withdrawn from the IBS by passing said part through a by-pass line (which by-passes the vaporizer) and spraying said part of cryogenic gas-liquid mixture into the vaporized cryogenic gas-liquid mixture with second spraying means located on a line exiting the vaporizer, i.e. a line being located downstream the vaporizer.

Preferably, the compressor is a centrifugal compressor.

To avoid depressurizing the system too much, a controllable vaporized liquefied gas stream can be fed via a liquefied gas vapor supply line to the system downstream the vaporizer and upstream the first spraying means. The liquefied gas vapor supply line then joins the line exiting the vaporizer upstream of the first spraying means. A pressure control valve located on the liquefied gas vapor supply line can be used to adjust the flow of the liquefied gas vapor stream and thus the pressure within the system.

To accelerate the vaporization of the LNG in the inter-barrier space and to withdraw the cryogenic gas-liquid mixture by gas-lift effect, the system can be operated below atmospheric pressure.

In a preferred embodiment, the pressure in the vaporization system is above 50kPa absolute.

According to a second aspect, the present invention relates to a method for vaporizing a cryogenic gas-liquid mixture, comprising the steps of:

- Withdrawing the cryogenic gas-liquid mixture from the inter barrier space of a cryogenic storage tank;
- Vaporizing the cryogenic gas-liquid mixture in a vaporizer;
- Spraying a cryogenic liquid into the vaporized cryogenic gas-liquid mixture to obtain a resulting cold mixture.
- Separating droplets of the cryogenic liquid from the cold mixture to obtain a resulting droplet-free mixture.
- Conducting the above steps under a depressurization created by the aspiration of a compressor.

Preferably, the temperature at the inlet of the compressor is controlled by a temperature control valve located on a cryogenic liquid supply line supplying the cryogenic liquid.

In a preferred embodiment, the pressure inside the system is controlled with a pressure control valve located on a liquefied gas vapor supply line joining the line exiting the vaporizer upstream the first spraying means.

In another embodiment, the pressure inside the system is controlled to be below atmospheric pressure.

In another preferred embodiment, the pressure inside the system is controlled to be in the range from 50 kPa absolute to atmospheric pressure.

A third aspect for which protection is sought, but which also represents an embodiment of the present invention according to the first and second aspects, is directed to a liquefied gas carrier comprising a system for vaporizing a cryogenic gas-liquid mixture according to claims 1 to 7.

Brief description of the drawings

Figure 1 schematically shows a first embodiment of the invention with first spraying means.

Figure 2 schematically shows a second embodiment of the invention with first and second spraying means.

Detailed description of the drawings

In the following, the different embodiments according to figure 1 and figure 2 are discussed comprehensively, same reference signs indicating same or essentially same units. It is appreciated that a person skilled in the art may combine certain components of an embodiment shown in a figure with the features of the present invention as defined in the appended claims without the need to include more than this certain component or even all other components of this embodiment shown in said Figures.

Figure 1 schematically shows a system 1 for vaporizing a cryogenic gas-liquid mixture according to the invention.

A cryogenic storage tank for LNG 4 with a first thin barrier of a metallic membrane and a second thin barrier of a metallic membrane, the two barrier being separated by a layer of a

porous cryogenic insulation material called inter-barrier space 3 is used on board a LNG carrier for storing and transporting LNG.

As the first thin barrier of a metallic membrane is in direct contact with the LNG inside the cryogenic tank 4, in case of rupture of the first thin barrier of a metallic membrane, LNG will accumulate inside the inter-barrier space 3.

During offloading of the tank, the liquid level inside the tank 4 can decrease faster than the liquid level inside the inter-barrier space 3. To avoid damaging the first thin barrier of a metallic membrane, dip tubes are provided within the IBS to drain the LNG accumulated.

During IBS draining, the accumulated LNG is lifted within the dip-tubes by gas lift effect in the form of a cryogenic gas-liquid mixture, the cryogenic gas-liquid mixture being a mixture of gaseous and liquid LNG.

The cryogenic gas-liquid mixture is supplied to the vaporizing system 1 according to the invention by a cryogenic gas-liquid mixture supply line 2 fluidically connecting the dip tubes and a vaporizer 5, where the cryogenic gas-liquid mixture is vaporized by indirect heat exchange with steam.

The vaporizer 5 is designed for yields higher than the ones required for IBS draining cases, so the vaporized cryogenic gas-liquid mixture may exit the vaporizer 5 at too high temperatures.

To avoid this, the vaporized cryogenic gas-liquid mixture leaving the vaporizer 5 and flowing through a line 16 is cooled down with a cryogenic liquid, in this embodiment with LNG, supplied by a cryogenic liquid supply line 6. The cryogenic supply line 6 is in fluid connection with the cryogenic tank 4 inner space in which the LNG is stored.

The vaporized cryogenic gas-liquid mixture leaving the vaporizer 5 and the cryogenic liquid form line 6 are mixed together with first spraying means 7 located downstream the vaporizer 5, where the cryogenic liquid is sprayed in the vaporized cryogenic gas-liquid mixture.

During spraying, the cryogenic liquid vaporizes within the vaporised cryogenic gas-liquid mixture, thereby reducing the vaporised cryogenic gas-liquid mixture to a temperature of the resulting mixture.

A mist separator 8 is provided downstream the first spraying means 7 to separate off remaining droplets of cryogenic liquid from the resulting cold mixture in case the cryogenic liquid is not totally vaporized in the resulting cold mixture.

A compressor 9 is provided downstream a gas outlet of the mist separator 8. The aspiration of the compressor 9 creates a depressurization within the system 1 which lowers the boiling point of the LNG, triggering the vaporization of the LNG inside the inter-barrier space IBS 3, the gas formed rising up the dip-tubes and lifting some liquid with it.

Because of the overall cryogenic temperatures within the system, it is advantageous to use a centrifugal compressor 9 as this type of compressor has less risks of machinery lube oil coming into contact with the compressed cryogenic gas, which could result in pollution of the compressed cryogenic gas, or freezing of the lube-oil.

However, as centrifugal compressors 9 are typically provided with impellers made of aluminium alloy, the temperature at the inlet of the compressor must be controlled to be below –50°C.

A temperature control valve 11 is provided on the cryogenic liquid supply line 6 upstream the first spraying means 7 to adjust the flow of cryogenic liquid sprayed into the vaporized cryogenic gas-liquid mixture in dependency of the temperature measured at the inlet of the compressor 9.

The pressure in the vaporizing system 1 of the invention is controlled to below atmospheric pressure by allowing a stream of a liquefied gas vapour, in this case natural gas (NG), to enter the vaporizing system 1. A pressure control valve 14 is provided on a liquefied gas vapour supply line 15 joining the line exiting the vaporizer 16 upstream of the first spraying means 7. With the pressure control valve 14, the flow of the liquefied gas vapour to the system 1 can be controlled. The pressure can be controlled to be within a range from 50kPa to atmospheric

pressure, as a pressure below 50 kPa can be damaging for the mechanical parts of the compressor 9.

Figure 2 schematically shows a system 1 for vaporizing a cryogenic gas-liquid mixture according to a second embodiment of the invention.

In addition to the first embodiment shown on figure 1, the second embodiment comprises second spraying means 12 located on the line exiting the vaporizer 16 upstream the first spraying means 7 and upstream the connection between the line exiting the vaporizer 16 the liquefied gas vapour supply line 15.

The second spraying means 12 can be used if the flow rate of cryogenic gas-liquid mixture supplied by the cryogenic gas-liquid mixture supply line 2 exceeds a certain value. A part of the cryogenic gas-liquid mixture will by-pass the vaporizer 5 through a vaporizer by-pass line 13, and will be mixed into the vaporized cryogenic gas-liquid mixture by means of the second spraying means 12 located downstream of the vaporizer 5 to decrease the temperature of the vaporized cryogenic gas-liquid mixture.

List of reference signs

1: system for vaporizing a cryogenic gas-liquid mixture

2: cryogenic gas-liquid mixture supply line

3: inter barrier space

4: storage tank

5: vaporizer

6: cryogenic liquid supply line

7: first spraying means

8: mist separator

9: compressor

10: gas outlet of the mist separator

11: temperature control valve

12: second spraying means

13: by-pass line of the vaporizer

14: pressure control valve

15: liquefied gas vapor supply line

16: line exiting the vaporizer

Claims

1. System (1) for vaporizing a cryogenic gas-liquid mixture comprising:
- A cryogenic gas-liquid mixture supply line (2) for withdrawing a cryogenic gas liquid mixture from an inter barrier space (3) of a cryogenic storage tank (4);
- A vaporizer (5) for vaporizing the cryogenic gas-liquid mixture, the vaporizer (5) being arranged downstream the cryogenic gas-liquid mixture supply line (1);
- A cryogenic liquid supply line (6);
- First spraying means (7) for spraying a cryogenic liquid from the cryogenic liquid supply line (6) into the vaporized cryogenic gas-liquid mixture downstream the vaporizer (5), obtaining a resulting cold mixture;
- A mist separator (8) for separating droplets of the cryogenic liquid from the cold mixture, the mist separator being located downstream the first spraying means (7);
- A compressor (9) located downstream a gas outlet (10) of the mist separator (8), the aspiration of the compressor (9) creating a depressurization within the system (1) for vaporizing the cryogenic gas-liquid mixture.

2. System (1) for vaporizing a cryogenic gas-liquid mixture according to claim 1, comprising a temperature control valve (11) located on the cryogenic liquid supply (6) line to control the temperature at an inlet of the compressor (9).

3. System (1) for vaporizing a cryogenic gas-liquid mixture according to any of claims 1 or 2, comprising second spraying means (12) for spraying a part of the cryogenic gas-liquid mixture passing through a by-pass line (13) of the vaporizer (5) into the vaporized cryogenic gas-liquid mixture exiting the vaporizer (5), the second spraying means (12) being located on a line exiting the vaporizer (16).

4. System (1) for vaporizing a cryogenic gas-liquid mixture according to any of claims 1 to 3, wherein the compressor (9) is a centrifugal compressor.

5. System (1) for vaporizing a cryogenic gas-liquid mixture according to claims 1 to 4, comprising a pressure control valve (14) located on a liquefied gas vapor supply line (15) to control the pressure within the system (1) for vaporizing a cryogenic gas-liquid mixture, the liquefied gas vapor supply line (15) joining the line exiting the vaporizer (16) upstream the first spraying means (7).

6. System (1) for vaporizing a cryogenic gas-liquid mixture according to claim 5, characterized in that the pressure inside the system (1) is below atmospheric pressure.

7. System (1) for vaporizing a cryogenic gas-liquid mixture according to claim 6, characterized in that the pressure inside the system (1) is in the range from 50kPa absolute to atmospheric pressure.

8. Method for vaporizing a cryogenic gas-liquid mixture, comprising the steps of:
- Supplying the cryogenic gas-liquid mixture from the inter barrier space (3) of a cryogenic storage tank (4);
- Vaporizing the cryogenic gas-liquid mixture in a vaporizer (5);
- Spraying cryogenic liquid into the vaporized cryogenic gas-liquid mixture and obtaining a cold mixture;
- Separating droplets of the cryogenic liquid from the cold mixture;
- Conducting the above steps under a depressurization created by the aspiration of a compressor (9).

9. Method for vaporizing a cryogenic gas-liquid mixture according to claim 9, wherein the temperature at the inlet of the compressor (9) is controlled by a temperature control valve (11) located on a cryogenic liquid supply line (6).

10. Method for vaporizing a cryogenic gas-liquid mixture according to claims 8 to 9, wherein the pressure inside the system (1) is controlled with a pressure control valve (14) located on a liquefied gas vapor supply line (15), the liquefied gas vapor supply line (16) joining the line exiting the vaporizer (15) upstream the first spraying means (7).

11. Method for vaporizing a cryogenic gas-liquid mixture according to claim 10, wherein the pressure inside the system (1) is controlled below atmospheric pressure.

12. Method for vaporizing a cryogenic gas-liquid mixture according to claim 11, wherein the pressure inside the system (1) is controlled in the range from 50 kPa absolute to atmospheric pressure.

13. Liquefied gas carrier comprising a system (1) for vaporizing a cryogenic gas-liquid mixture according to claims 1 to 7.