LIQUEFIED GAS STORAGE DEVICE

TECHNICAL FIELD

The invention relates in particular to a liquefied gas storage device, in particular for a liquefied gas carrier or for a land-based facility.

STATE OF THE ART

In order to more easily transport gas, such as natural gas, over long distances, the gas is usually liquefied (to become liquefied natural gas - LNG) by cooling it to cryogenic temperatures, for example -160°C at atmospheric pressure. The liquefied gas is then loaded into carriers, such as LNG carriers and bunker vessels.

In order to limit the boil-off of the liquefied gas contained in a tank of a ship, it is known practice to store it under pressure in this tank so as to move on the vaporization curve of the considered liquefied gas, thus increasing its vaporization temperature. The liquefied gas can thus be stored at higher temperatures, which results in limiting the boil-off of the gas.

The natural evaporation of gas is inevitable, however, this phenomenon being called NBOG, which is the acronym of *Natural Boil-Off Gas* (as opposed to the forced evaporation of gas, or FBOG, acronym of *Forced Boil-Off Gas*). The gas which evaporates naturally in the tank of a ship is generally used to supply an energy production installation of the ship, which is intended to meet the energy requirements for the operation of the ship, in particular for the propulsion of the ship and/or the production of electricity for on-board equipment.

In the current technique, the improvement of the tanks are such that the natural Boil-Off Rates (BOR) of the liquefied gases are increasingly low, while the machinery of a ship is increasingly more efficient. As a result, the difference is very large between the quantity of gas naturally produced by boil-off and that which is required by a ship’s installation. The excess gas is particularly significant when the ship's consumption is low, that is to say for example when the ship is idling, is in the standby phase, or is in a damaged state for instance

affecting the treatment equipment or in which consumption figures are no longer available.

The excess natural boil-off gas (NBOG) is then recondensed and reinjected into the tank. Re-liquefaction or re-condensation means are used for this, which transform the NBOG into liquefied gas which is then reinjected into the tank.

It is also possible to reduce NBOG production by reducing the temperature of the gas overhead contained in the tank above the liquid-gas interface in the tank. To do this, it is possible to draw off liquefied gas, cool it (or sub-cool it because it is already very cold), then reinject it into the tank via liquefied gas spray bars in the gas overhead.

This makes it possible to control the pressure in the tank by re-condensing BOG in the gas overhead (first objective). This also makes it possible to control the temperature of the liquefied gas in order to deliver "cold" LNG (second objective). Indeed, in the context of an LNG carrier or bunker vessel, a maximum temperature of LNG to be delivered may be required by the receiving terminal or ship.

The first objective mainly responds to the LNG transfer operation between several storage facilities of the same installation and/or between several storage facilities of several installations, in order to condense the excess gas generated during the LNG transfer operation, in order to carry out the transfer in a given time. The first objective can also meet the need for a loaded or nearly empty tank (if the goal is to control the pressure).

The second objective responds to the request of the bunkered vessel to receive relatively cold LNG in order to maintain a safety margin in relation to the safety valves. After the bunker loading operation, the charterer will therefore want to keep his cargo as cold as possible, or even cool his cargo in order to respect his contract with the LNG-powered ship. He will therefore use his sub-cooling equipment to cool the LNG and prevent the pressure from dropping.

One of the objectives of the present invention is to optimize the storage in the liquefied gas tank according to the desired need, in particular for controlling a pressure or controlling a liquid temperature.

DISCLOSURE OF THE INVENTION

According to a first aspect, the invention proposes a liquefied gas storage device, in particular for a liquefied gas carrier or for a land-based facility, comprising:

- at least one liquefied gas storage tank that has a tank bottom and a tank ceiling which together define a tank height,
- means for drawing off gas, in liquid and/or gaseous form, in said tank, and
- means for injecting gas in liquid form into said tank, which means are preferably connected to the gas draw-off means,

characterized in that said gas injection means comprise at least one injector-mixer which is located in a lower zone of said tank extending between 0 and 25%, preferably between 0 and 15%, and more preferably between 0 and 10%, of the tank height measured from said tank bottom, and which is intended to be immersed in said liquefied gas contained in the tank.

Preferably, said at least one injector-mixer is configured to inject a flow of liquid gas in a direction which is inclined upwardly at an angle α relative to a horizontal plane. Said angle α may be between 5° and 45°, preferably between 5° and 30°, and more preferably between 5° and 20°. In a variant, the angle α may be between 5° and 85°, preferably between 15° and 75°, and more preferably between 30° and 60°.

According to a second aspect, the invention proposes a liquefied gas storage device, in particular for a liquefied gas carrier or for a land-based facility, comprising:

- at least one liquefied gas storage tank that has a tank bottom and a tank ceiling which together define a tank height,
- means for drawing off gas, in liquid and/or gaseous form, in said at least one tank, and
- means for injecting gas in liquid form into said tank, which means are preferably connected to the gas draw-off means,

characterized in that said gas injection means comprise at least one injector-mixer which is located in an upper zone of said tank extending between 60 and

100%, or even between 75 and 100%, preferably between 60 and 98%, and more preferably between 65 and 95%, or even more preferably between 65 and 80%, or between 80 and 95%, of the tank height measured from said tank bottom, and which is intended to be immersed in said liquefied gas contained in the tank.

Preferably, at least one injector-mixer is configured to inject a flow of liquid gas in a direction which is inclined downwardly at an angle β relative to a horizontal plane. Said angle β may be 5° and 45°, preferably 5° and 30°, and more preferably between 5° and 20°. In a variant, the angle β may be between 5° and 85°, preferably between 15° and 75°, and more preferably between 30° and 60°.

Advantageously, said at least one injector-mixer is fixed to a wall of said tank. Preferably, said tank comprises a vertical longitudinal side wall connected by a slanted wall to said tank ceiling, said at least one injector-mixer being fixed to a zone for connecting said vertical longitudinal wall to said slanted wall. Said at least one injector-mixer can be fixed to a thickened metal sheet and/or to at least one wooden block of said connection zone. This sheet may form part of a membrane of the tank and therefore be, as is the case with the membrane, in contact with the liquefied gas contained in the tank (when liquefied gas is present in the tank, or at least in the absence of leakage). The block of wood can be located between this membrane and the hull of the ship.

In each of the above aspects, the key principle sought is to be able to reinject liquefied gas, which may or may not be sub-cooled beforehand, into the liquid and not into the gas overhead contained in the tank. In fact, reinjecting the majority of the cold power into the gas overhead will result in a significant drop in pressure and the cooling of the gas overhead, which will force the reentering heat flow into the upper part of the tank. A significant part of the liquefied gas reinjected into the gas overhead would then be unnecessarily vaporized, which would limit the cold power supplied to the liquid. This is especially true inasmuch as the latter will be distributed only to the free surface of the liquid, which would cause the diffusion kinetics to be slow. On the contrary, the invention proposes to reinject the cold power directly into the liquid under the

free surface in order to reduce the influence on the temperature and the pressure of the gas overhead. In addition, injecting liquefied gas under the free surface makes it possible to create a mixing and stirring effect by adjusting the kinetics of the liquid at the outlet of the injector-mixer, its orientation, its elevation, etc. The invention also relates to the case where the liquefied gas is not necessarily sub-cooled before it is injected into the tank. The main function of the injection of liquefied gas would then be to mix the liquefied gas contained in the tank. This is particularly useful for limiting the boil-off of the liquefied gas, in particular when the sub-cooled liquefied gas is poured into the tank bottom, this sub-cooled liquefied gas being obtained by reliquefaction of boil-off gas. The forced boil-offs from the tank are much richer in nitrogen compared to the liquid that boils off naturally (because of the volatility of nitrogen compared to methane). The boiled off gas is liquefied by reliquefaction means and returned to the bottom of the tank. The condensate is therefore much heavier than the surrounding liquefied gas (because it is richer in nitrogen, but also cooler). Nitrogen-rich liquid collects at the bottom of the tank. As it warms up naturally, nitrogen bubbles vaporize and rise to the surface, which enriches the gas overhead with nitrogen. However, nitrogen is difficult to condense, which reduces the capacity of the liquefier and causes difficulties in controlling the pressure in the tanks. The phenomenon is amplified when the tank is almost empty because the nitrogen bubbles do not have time to re-dissolve during the rise to the surface. This is why injection by spray bars at the top of the tank is never considered with this type of equipment, due to the risk of nitrogen enrichment. When using an almost empty tank, this phenomenon generates aging of the heel, which limits the capacity of the heel to cool the tanks before the next loading.

The invention also relates to the case where the liquefied gas is overheated before it is injected into the tank. The main function of the injected liquefied gas would then be to be mixed with the liquefied gas contained in the tank. This is particularly useful for limiting the boil-off of said superheated liquefied gas, in particular when it is poured into the bottom of the tank. Said superheated liquefied gas being hotter and therefore lighter than the

surrounding liquefied gas (which is colder), this liquefied gas would boil off without a mixing device, even by being injected at the bottom of the tank. Indeed, being lighter, it would rise in the surrounding liquid, which is colder and therefore heavier, until it boils off when its static pressure becomes lower than its bubble point pressure. This is particularly true in the case where the liquid level in the tank is low because the static pressure at the bottom of the tank is lower compared to a higher liquid level. Using a mixing device by the Venturi effect, suction, entrainment, etc., is particularly suitable for the injection of said superheated liquefied gas because it allows a dilution of at least 4 times. This superheated liquefied gas is obtained by recondensation (that is to say, mixing) of pressurized boil-off gas with liquefied gas coming from a tank. The superheated liquefied gas is normally vaporized for injection into the land-based gas network. If the land-based gas network asks the vaporization unit to stop sending to the network, the superheated liquefied gas can then be returned to the tank via the mixing device while limiting the natural boil-off of the gas stored in the tank. Without a mixing device, the boil-offs generated by the injection of said superheated liquefied gas into the tank generate additional boil-offs which are added to the natural boil-offs which must then be recondensed in order to be reinjected into the tank. This results in accelerated heating of the liquefied gas contained in the tanks, and therefore a more rapid rise in pressure compared to the use of a mixing device.

The injection of liquefied gas here is carried out by means of an injector-mixer which is configured to inject a flow of liquid gas and to cause it to mix with the liquid in which it is injected by the Venturi effect, suction, entrainment, etc.

The device according to the invention can comprise one or more of the following features, taken in isolation from one another or in combination with one another:

- said at least one injector-mixer is located as close as possible to a longitudinal side wall of said tank; in the present application, the term “closest” or “close” is understood to mean a distance of less than one meter, and preferably less than or equal to 0.5 meters, or even less,

- said injection means comprise at least one horizontal row of injector(s)-mixer(s) which are configured to inject flows of liquid gas in parallel or different directions,

- said injection means comprise at least two horizontal rows of injectors-mixers which are arranged respectively on and/or along two longitudinal side walls of said tank,

- said gas injection means are connected by reliquefaction means to means for drawing off gas in said tank or in another tank,

- said reliquefaction means are configured to recondense boil-off gas drawn off from said tank or from another tank and then pressurized, by heat exchange with liquefied gas drawn off from said tank or from another tank,

- said gas injection means are connected by sub-cooling means to means for drawing off liquid gas from said tank or from another liquefied gas storage tank,

- said draw-off means are configured to draw off liquid gas from said lower zone,

- said draw-off means comprise at least one pump and pipes located in said tank or in another tank and intended to be at least partly submerged in said liquefied gas,

- said pump is configured to have a variable flow rate or rotor speed,

- said tank is of the “all-fill” type and is configured to be filled to any level,

- said tank is of the “restricted filling” type and is configured to be filled only to 10% and less, or to 70% and more,

- said draw-off means and said injection means are located in said tank and connected to each other by pipes located entirely in the tank,

- the pipes extend at least partly substantially parallel to and near a bottom wall of the tank, and preferably up to at least one side wall of this tank,

- in the event that the draw-off means are located in the center and at the bottom of the tank, pipes may extend in opposite directions along the bottom wall and up to the side walls of the tank,

- the pipes can be configured to match the specific shape of the tank bottom and in particular any connecting chamfers between the bottom and side walls of the tank.

- said draw-off means and said injection means are located perpendicular to a liquid dome of said tank, and preferably equip a pump tower which is accessible by this liquid dome,

- said at least one injector-mixer is connected to a liquid column of said pump tower, and supported by this column,

- said injector-mixer comprises a main pipe for passage of a main jet of liquid, and a secondary pipe for forced passage of a secondary jet of liquid by the Venturi effect,

- said injection means, or even also said draw-off means, are positioned relative to one another and configured so that they generate back pressure and suction effects in the tank, these effects generating a predetermined stirring cycle of the liquefied gas in the tank.

The present invention further relates to a liquefied gas carrier, comprising at least one device as described above, this device being devoid of sub-cooling and reliquefaction means between said draw-off and injection means, said tank being of the “all-fill” type and being configured to be filled to any level.

The present invention further relates to a liquefied gas carrier, comprising at least one device as described above, this device comprising means for sub-cooling and/or reliquefaction between said draw-off and injection means, said tank being of the “all-fill” or “restricted fill” type.

The present invention further relates to a liquefied gas carrier, comprising at least one device as described above, this device being devoid of sub-cooling and reliquefaction means between said draw-off and injection means, said tank being of the “restricted fill” type and being configured to be filled only to 10% and less, or to 70% and more.

The present invention further relates to a liquefied gas carrier, comprising at least one device as described above, this device comprising sub-cooling and/or reliquefaction means between said draw-off and injection means, said tank being of the “restricted fill” type and being configured to be filled only to 10% and less, or to 70% and more.

In the case of an injection in the lower part of the tank, said injection means is or are oriented upwards in order to generate back pressure and suction effects in the tank and to generate a stirring cycle both for an almost empty tank ("ballast") and for an almost full tank ("laden"). In the case of an almost empty tank (liquid heel), this configuration makes it possible to stir the liquid over the majority of the length of the tank (sufficiently low angle, that is to say close to the horizontal), without, however, dispersing the liquid in the gaseous gap because this would cool the gas and therefore increase heat transfers. Too great an angle (that is to say close to the vertical) would generate an accumulation of the injected liquid close to the injector and the draw-off means and would enable a re-sampling of the injected liquid toward sub-cooling means with the risk of freezing of the sub-cooled liquid (in the case of a combination with sub-cooling means located between the draw-off and injection means).

In the case of an almost full tank, this configuration makes it possible to stir the liquid over the majority of the height of the tank (sufficiently large angle, that is to say close to the vertical), so that the temperature of the liquid is homogeneous over the entire height of the liquid. Too small an angle (that is to say close to the horizontal) would generate an accumulation of the injected liquid at the bottom of the tank and close to the draw-off means and would enable a re-sampling of the injected liquid toward sub-cooling means with the risk of freezing of the sub-cooled liquid (in the case of a combination with sub-cooling means located between the draw-off and injection means). There is also the risk of suddenly depressurizing the tank in the event of homogenization of the sub-cooled liquid which would have accumulated at the bottom of the tank, with possible opening of the safety valves if the pressure drops below atmosphere.

The present invention also relates to a method for injecting gas in liquid form into a tank of a ship as described above.

According to a first embodiment, the injection (in the lower zone) takes place when the “restricted fill” tank is filled to 10% or less.

According to a variant embodiment, the injection takes place when the “all-fill” tank has any level of filling, the injection angle (in the lower zone) being identical irrespective of this level and the injection rate being controlled according to this level. Preferably, the greater the volume of liquid in the tank, the greater the injection rate.

The present invention also relates to a method of injecting gas in liquid form into a tank of a ship as described above, in which the injection into the upper zone takes place when the "restricted fill" tank is filled to 70% or more.

The present invention also relates to a method of injecting gas in liquid form into a tank of a ship as described above, in which the injection into the tank is configured to prevent heated liquefied gas from rising along the longitudinal side walls of this tank.

The present invention also relates to a method for injecting gas in liquid form into a tank of a ship as described above, in which the injected liquefied gas has a temperature lower than that of the liquefied gas contained in said tank.

Advantageously, said injection means, or even also said draw-off means, are controlled so that they generate back pressure and suction effects in the tank, these effects generating a predetermined stirring cycle of the liquefied gas in the tank. The stirring cycle is advantageously designed so that liquefied gas circulates substantially parallel to the liquid-gas interface in the tank, and close to this interface. This makes it possible to limit the risk of a hot liquid layer forming at the interface, and therefore of boil-off of the liquefied gas.

In the present application:

- “tank” refers to any tank having an internal liquefied gas storage volume greater than 100 m^3, and preferably greater than 1,000 m^3, or even 10,000 m^3, or even 20,000 m^3; and/or any tank configured to store liquefied gas at a temperature of -163°C or even less,
- tank of the “all-fill” type refers to a tank which is configured to store any volume of liquefied gas, which may for example represent 50% of its total internal volume; a ship of the FSRU (*Floating Storage Regasification Unit*), ST (*Shore Tank*), GBS (*Gravity Base Structure*),

LBV (*LNG Bunker Vessel*), LFS (*LNG Fueled Ship*) type is generally equipped with such a tank,

- tank of the "restricted fill" type refers to a tank which is configured to store a volume of 10% and less, and 70% and more, of liquefied gas; it is therefore not designed to store an intermediate volume of liquefied gas, for example representing 50% of its total internal volume, in particular for safety reasons, which is the case of an LNG vessel that is liable to be subjected to transport conditions during a journey which may cause wave movements of the liquefied gas in the tank; an LNGC-type vessel (LNG carrier) is generally equipped with such a tank,
- "ship" refers to any unit for the maritime transport of liquefied gas, such as an LNG carrier, a bunker vessel, etc.,
- "reliquefaction means" or "recondensation means" refers to means configured to cause the condensation of gas and therefore the transformation of this gas into liquefied gas, the gas generally being BOG or NBOG; they can for example comprise means for compressing gas under temperature and pressure conditions allowing its condensation,
- "sub-cooling" means refers to means configured to further cool the liquefied gas, which is generally already at a temperature of -163° C or even less, the sub-cooling making it possible, for example, to reduce the temperature of the liquefied gas by about 10°; sub-cooling means, for example, comprise means for boiling off or vaporizing liquefied gas to generate cooling energy, and means for exchanging heat with liquefied gas so that the latter is sub-cooled owing to this energy,
- the concepts of "up" and "down" or of "upper" and "lower" are assessed in relation to the conventional position, that is to say of operation, of a ship when it is landed and floating on water, and more generally in relation to the center of the earth (the top being further than the bottom from the center of the earth).

BRIEF DESCRIPTION OF THE FIGURES

The invention will be better understood and other details, features and advantages of the present invention will emerge more clearly on reading the following description, given by way of non-limiting example and with reference to the appended drawings, in which:

- Fig. 1 is a schematic longitudinal sectional view of a first embodiment of a liquefied gas storage device according to the invention,
- Fig. 2 is a schematic cross-sectional view of the device of Fig. 1,
- Fig. 3 is a larger-scale view of part of Fig. 1,
- Fig. 4 is a schematic longitudinal sectional view of a second embodiment of a liquefied gas storage device according to the invention,
- Fig. 5 is a schematic cross-sectional view of the device of Fig. 4,
- Fig. 6 is a larger-scale view of part of Fig. 4,
- Fig. 7 is a schematic perspective and sectional view of a liquefied gas storage tank,
- Fig. 8 is a schematic perspective view of a connecting zone of walls of a tank, such as that of Fig. 7,
- Fig. 9 and 10 are very schematic partial views of tanks having different geometries,
- Fig. 11 and 12 are very schematic sectional views of variant embodiments of the device according to the invention, Fig. 9 showing a sectional view of the middle of this device, and Fig. 10 showing a sectional view of each longitudinal end of this device,
- Fig. 13 is a very schematic top view of a variant embodiment of the device according to the invention,
- Fig. 14 to 26 are very schematic sectional views of variant embodiments of the device according to the invention,
- Fig. 27 and 28 are schematic views, respectively in section and in perspective, of an exemplary embodiment of an injector-mixer,
- Fig. 29 is a block diagram illustrating several embodiments of a ship and of a method according to the invention,

- Fig. 30 and 31 are views similar to that of Fig. 4 and show the same tank which is respectively in “ballast” and therefore filled with a liquid heel, and in “laden” and is almost completely filled.

DETAILED DESCRIPTION

As mentioned in the foregoing, the temperature and the pressure in a liquefied gas (LNG) storage tank can be controlled in particular in order to control the production of NBOG in the tank.

A liquefied gas storage device, in particular for a liquefied gas carrier, generally comprises:

- at least one liquefied gas storage tank,
- means for drawing off gas, in liquid and/or gaseous form, in the tank, and
- means for injecting gas in liquid form into the tank, which means are connected to the gas draw-off means.

As part of the first objective mentioned above, the gas overhead is cooled using sub-cooled LNG spray bars. LNG is drawn off by the draw-off means, is sub-cooled by sub-cooling means, then is injected by the bars (injection means) at the top of the tank. Spraying makes it possible to directly impact the temperature and pressure of the gas overhead by maximizing the exchange surface between the droplets and the gas in order to condense it.

In practice, two spray bars are conventionally available and identical: they are generally used simultaneously to carry out the initial cooling, whereas a single bar makes it possible to carry out normal cooling (ballast) before loading.

If this device is used for a full tank, the sub-cooled LNG is sprayed mainly on the liquid-gas interface, which is not very suitable if the aim is to impact the temperature of the liquid over the entire height of the tank and therefore the entire volume of liquid.

If one or two bars are used in the case of ballast (tank with liquid heel), the temperature of the gas overhead (including the ceiling) is therefore very cold (close to equilibrium = dew point temperature) and the heat flow through the insulation from the outside is therefore increased. Without spraying sub-cooled gas using the bars, the gas overhead is significantly stratified in temperature (hotter gas is concentrated at the top and colder gas is concentrated at the

bottom), which reduces boil-off, and therefore the cold power necessary to control the pressure and temperature in the tank. If sub-cooling means are used in the case of a ballast when the gas overhead has warmed up, in addition to increasing the heat flow, the spraying of sub-cooled liquid could result in increasing the tank pressure, because the dispersed LNG would evaporate while cooling the insulation of the heated tank.

In the context of the second objective, which is to control or even cool the stored LNG, the ideal would be to re-inject sub-cooled LNG into the tank. However, the sub-cooled LNG would be returned directly to the tank without being mixed with the LNG which is already present in the tank. Furthermore, the LNG subcooled by around 10° would be heavier than the LNG in the tank and would have difficulty mixing with the latter. In the event that the sub-cooled LNG is reinjected at the bottom of the tank, it would concentrate at the bottom of the tank and could be directly drawn off again by the abovementioned draw-off means, which would adversely affect the efficiency of the sub-cooling. Indeed, this would amount to drawing off LNG which has already been sub-cooled and whose sub-cooling would tend to cool the LNG too much because the output temperature of the sub-cooling means is limited in order to avoid freezing of the LNG (mainly heavy compounds). Consequently, it would be necessary to reduce the instantaneous power of the sub-cooling means. However, in order not to limit this power (and to avoid the recirculation of sub-cooled LNG) and to reduce the electrical consumption of the equipment (to avoid cooling the gas overhead), the invention proposes to inject the sub-cooled LNG below the liquid-gas interface and via at least one injector-mixer.

Fig. 1 to 3 illustrate one of the aspects of the invention in which the gas injection means comprise at least one injector-mixer 10 which is located in an upper zone of the tank 12 extending between 60 and 100% of the height of the tank measured from the bottom of the tank 14. The height of the tank 12 is measured between the tank bottom 14 and the tank ceiling 16. Reference 18 designates the liquid-gas interface or the free surface of the liquefied gas in the

tank, the liquid formed by the liquefied gas being heavier and therefore under the gas overhead which is formed by natural boil-off of the liquefied gas.

In addition to the tank 12 and the injector-mixer 10, the liquefied gas storage device comprises means for drawing off gas, here in liquid form. The draw-off means here comprise a pump 20 which is submerged in the liquefied gas and is preferably located at the bottom of the tank. The liquefied gas can be drawn off and injected into the same tank, or into a different tank.

The pump 20 is connected to the injector-mixer 10, directly or by means of sub-cooling means 22. The sub-cooling means can be configured to decrease the temperature of the liquefied gas drawn off by the pump, by approximately 10°.

The tank 12 may be of the “all-fill” type or of the “restricted fill” type. In both cases, when it is filled with liquefied gas (and does not include a liquefied gas heel at the bottom of the tank), it is filled to at least 70% of its volume. In practice, it is filled to a volume of 95% or more, and preferably 98.5%.

The injector-mixer 10 is positioned and designed to inject liquefied gas that is drawn off (and possibly sub-cooled) below the interface 18, so that the flow of liquefied gas mixes the liquefied gas contained in the tank 12.

Advantageously, the injector-mixer 10 is configured to inject a flow of liquefied gas in a direction which is inclined downwards at an angle β with respect to a horizontal plane (Fig. 3). The angle β is for example between 5° and 85°, preferably between 15° and 75°, and more preferably between 30° and 60°.

This makes it possible to facilitate the mixing of the liquefied gas in the tank, over substantially the entire height of the liquefied gas and over the greatest possible distance, as is schematically shown by the arrows in Fig. 1.

In the case of an injection of sub-cooled or superheated liquefied gas, that is to say from sub-cooling equipment or a re-condenser presented above, the injector(s)-mixer(s) can advantageously be fixed to the pump tower.

The tank 12 has a general parallelepipedal and elongated shape, but can also be chamfered, as shown in Fig. 1 and 2. The tank 12 comprises a rear longitudinal end 12a and a front longitudinal end 12b, the terms “rear” and

“front” referring to the rear and the front of the carrier and to its direction of travel. The tank further comprises longitudinal side walls 12c.

In the illustrated example, the pump 20 and the injector-mixer 10 are located at the rear end 12a of the tank 12.

The injector-mixer 10 is configured to inject a flow of liquefied gas forward so as to promote good mixing of the liquefied gas in the tank. In the event that the injected liquefied gas were to be sub-cooled, it would be colder and therefore heavier than that in which it is injected, which justifies the positioning in the upper part of the tank slightly below the surface and oriented slightly downwards and a relatively low angle β so as to mix the front of the tank as much as possible. This makes it possible to limit the recirculation of sub-cooled liquefied gas to the pump 20, and the spraying of the tank wall opposite the injector-mixer 10. Furthermore, the injection at the top of the tank further favors mixing by diffusion by gravity because the sub-cooled liquefied gas has a density slightly greater than that in the tank and will therefore flow slowly downward. An injection just below the nominal liquid level when the tank is loaded will therefore be sought, but sufficiently below the free surface so as not to suck gas from the gas overhead, in particular by the Venturi effect.

The pump 20 and the injector-mixer 10 can be located substantially perpendicular to a “liquid dome” of the tank, schematically shown by the capital letters LD. In this case, the pump 20 and the injector-mixer 10 can be connected to vertical pipes of a “pump tower.” These pipes can then support the injector 10.

Alternatively, the injector-mixer 10 can be fixed to one side of the tank 12. Fig. 7 shows a more precise example of the general shape of a tank 12 for storing liquefied gas. This tank comprises a longitudinal side wall 12c which is vertical, and which is connected by slanted walls 12d, 12e, respectively to the tank ceiling 16 to to the tank bottom 14. The dimensions of the walls 12c, 12d and 12e are variable, as is schematically shown in Fig. 9 and 10. In these drawings, reference H designates the height of the tank mentioned above, and measured between the tank bottom 14 and the tank ceiling 16. H is for example greater than or equal to 15 m, and may be 27 m, for example.

The tank 12 is generally of the membrane type, that is to say that its walls 12c, 12d and 12e, as well as its bottom 14, are formed by a succession of layers comprising, for example, from the inside of the tank towards the outside, a sheet metal membrane, insulation, a sheet metal membrane, insulation, then the hull of the ship. In the connecting zones of the walls 12c, 12d and 12e, such as the zone identified by the arrow in Fig. 7, the tank is reinforced by structures comprising wooden blocks 30 and metal reinforcements 32 made of sheet metal which is thickened compared to the sheet metal used for the membranes.

The reinforcements 32 may form part of the membrane of the tank which is in contact with the liquefied gas contained in the tank. The tank may comprise a single membrane and the reinforcements 32 then form part of this membrane, or else the tank comprises two membranes, primary and secondary respectively, between which an insulating layer is placed, and the reinforcements 32 then form part of the primary layer and are therefore intended to be in contact with the liquefied gas.

The block of wood 30 can be located between the (primary) membrane of the tank and the hull of the ship.

The injector-mixer 10 of the device can be fixed to the tank 12 in such a connection zone, such as that between the side wall 12c and the slanted wall 12d, as is schematically shown in Fig. 9 and 10.

As mentioned in the foregoing in relation to Fig. 1 to 3, the injector-mixer 10 is positioned so that it can result in a mixture of an optimal volume of liquefied gas in the tank. The power of the injector-mixer, that is to say the flow rate of liquid flow that it can deliver, depends in particular on the power of the pump 20. Advantageously, this pump is the one already fitted to the tank and in particular the aforementioned pump tower and therefore has a limited power, for example less than or equal to 100 m^3/h, and for example less than or equal to 60 m^3/h.

The pump could be of the type with variable speed and therefore variable flow. This makes it possible in particular to adapt the power of the pump, and therefore the flow rate of the liquid flow injected by the injector-mixer, to the volume of liquefied gas in the tank and therefore to the filling level of the tank.

To remedy this and allow mixing of the total volume of liquefied gas in the tank, it is possible to equip the tank with several injector-mixers 10.

In all of the concepts illustrated by Fig. 9 to 20, that is to say in which the injector-mixer bars are located at the top of the tank, under the liquid surface, the injectors-mixers are advantageously positioned close to the vertical walls of the tank, because one of the objectives is to prevent the rise of the LNG heated by the vertical walls. In fact, the LNG in the tank is heated near the vertical walls. As it becomes hotter than the surrounding LNG, it becomes lighter and therefore rises along the vertical walls. As shown in Fig. 13, which is a top view of a tank, the annular space inside the tank, in contact with the vertical walls, is where the heated LNG rises. Without a mixing device, the heated LNG reaches the surface and forms a hotter liquid layer at the surface, which preferably boils off, despite the fact that the deep LNG is colder than the surface LNG. This boil-off increases the pressure in the tank. Positioning the injector(s)-mixer(s) bars in the liquid in the upper part therefore makes it possible to prevent the heated liquid from rising and the hot liquid layer from forming on the surface.

Fig. 13 shows an example tank 12 equipped with several injectors-mixers 10 which are distributed in two horizontal rows respectively on the two longitudinal sides of the tank. This tank is seen from above, the reference LD designating the liquid dome and the reference GD designating the gas dome of the tank. Line T1 represents the connection zone between the slanted wall 12d and the tank ceiling 16, and line T2 represents the connection zone between this slanted wall 12 and the side wall 12c. Injectors-mixers 10 are evenly distributed over this zone, along the tank.

The injectors-mixers 10 of a tank or row may have similar or different orientations. In the embodiment of Fig. 13, the two injectors-mixers 10 located at the longitudinal ends of the tank on each row are oriented toward the tank bottom, at an angle βmin, for example between 0° and 45° (Fig. 12), preferably between 0° and 30°, and more preferably between 5° and 15°. This angle makes it possible to mix as much liquefied gas as possible close to the vertical transverse wall because it is close to the vertical surfaces that the liquefied gas heats up and then rises towards the surface to form the hot liquid layer, the

formation of which is to be avoided. The other injectors-mixers located between those located at the longitudinal ends of the tank in each row are oriented toward the tank bottom, at an angle βmax, which is greater than βmin, and for example between 45° and 90°, preferably between 70° and 90°, and more preferably between 80° and 85° (Fig. 11).

As can be seen in Fig. 11 and 12, it is better to control the angle β so as to mix the minimum of liquefied gas in the tank, and the maximum of liquefied gas in contact with the vertical walls. If the angle is too small and the injectors-mixers inject liquefied gas directly toward the center of the tank, the risk is of mixing a large central volume of liquefied gas from the tank, schematically designated by reference V. However, mixing a large volume of liquefied gas requires significant pumping power, which would have the unwanted effect of reheating the liquefied gas and therefore increasing the pressure in the tank more rapidly.

In the case of Fig. 11, the liquid surface layer is sucked up and discharged at a depth in order to mix it with the cargo. The downward inclination of the injectors-mixers 10 allows this liquid surface layer to be sucked up and a small volume to be mixed. The injectors-mixers located at the front and at the rear of the tank are oriented toward the center of the tank in order to prevent the rise of LNG heated by the vertical front and rear walls.

Fig. 14 illustrates a case where the injectors-mixers are oriented toward the top of the tank and do not allow a smaller volume of liquefied gas contained in the tank to be mixed. The liquid layer is effectively broken due to the proximity of the injectors-mixers to the surface, which advantageously reduces the power required to renew this liquid surface layer, but the low pumping power still risks heating the LNG which remains in the upper part of the tank. The position of the injectors-mixers is advantageously made possible due to the presence of the reinforced angle (connection zone described above) between the vertical wall and the oblique upper wall. The injectors-mixers are oriented toward the top of the tank, at an angle βmax, which is greater than βmin, and for example between 0° and 60°, preferably 0° and 30°, and more preferably 15° and 30° (Fig. 14).

Fig. 15 and 16 illustrate other cases where the injector-mixer of a first lateral row, and the injector-mixer of the second lateral row and located opposite the injector-mixer of the first row, do not have the same orientations. In the case of Fig. 15, the liquid layer is effectively broken due to the proximity of the injectors-mixers to the surface which advantageously makes it possible to reduce the power required to renew this liquid surface layer, but the low pumping power still risks heating the LNG which remains in the upper part of the tank. A first injector-mixer bar oriented upward delivers liquefied gas toward the second injector-mixer bar which is laterally opposite and oriented horizontally, which delivers it toward the first injector-mixer bar. The first injectors-mixers are oriented toward the top of the tank, at an angle βmax, which is greater than βmin, and for example between 0° and 60°, preferably between 15° and 60°, and more preferably between 30° and 45° (Fig. 15). The second injectors-mixers are oriented toward the bottom of the tank, at an angle βmax, which is greater than βmin, and for example between 0 and 30°, and preferably between 0° and 15° (Fig. 15). The mixed volume seems low. The two bars working together favor a lower mixing power. In the case of Fig. 16, the particularity compared to the case of Fig. 15 is the orientation of the second injector-mixer bar, which is advantageously oriented downward by an angle β so as to discharge at a depth and mix the liquid surface layer with the LNG from the cooler bottom. β is comprised between βmax, which is greater than βmin, and is for example between 90° and 30°, preferably between 90° and 60°, and more preferably between 85° and 75° (Fig. 16). The mixed volume seems low. The two bars working in concert favor a lower mixing power and therefore low heating linked to the pumping.

However, injectors-mixers 10 having different orientations can be associated with one another so that the entire volume of liquefied gas stored in a tank is effectively mixed and therefore impacted by the liquefied gas injected into the tank.

Fig. 17 to 20 illustrate several possibilities for supplying the injectors-mixers. Fig. 17 illustrates the case where the rows on both sides are supplied in

parallel. Fig. 18 illustrates the case where the rows on both sides are supplied independently. Fig. 19 illustrates the case where the tank comprises one or more row(s) whose supply pipes 34 pass through a wall of the tank, and Fig. 20 illustrates the case where the tank comprises one or more row(s) whose supply pipes 34 do not pass through the wall of the tank. The pipes 34 are then housed, with the pump and the injectors-mixers, in the tank, so as to have a fully autonomous system. This is particularly interesting because, in the case of ships powered by LNG, the code may require isolating the tank in the event of damage to the ship or part of the ship, and the mixing system would then no longer be operational if the tank were isolated.

Fig. 4 to 6 illustrate another of the aspects of the invention in which the gas injection means comprise at least one injector-mixer 10 which is located in a lower zone of the tank 12 extending between 0 and 25% of the height of the tank measured from the bottom of the tank 14.

In addition to the tank 12 and the injector-mixer 10, the liquefied gas storage device comprises means for drawing off gas, here in liquid form. The draw-off means here comprise a pump 20 which is submerged in the liquefied gas and is preferably located at the bottom of the tank.

The liquefied gas can be drawn off and injected into the same tank, or into a different tank.

The pump 20 is connected to the injector-mixer 10, directly or by means of sub-cooling means 22. The sub-cooling means are for example of the aforementioned type. The sub-cooling means can be configured to decrease the temperature of the liquefied gas drawn off by the pump by approximately 10° C.

The tank 12 may be of the “all-fill” type or of the “restricted fill” type. In both cases, it can be filled with a liquefied gas heel at the bottom of the tank, representing at most 10% of the total internal volume of the tank. In the case of an all-fill tank, this tank can include any volume of liquefied gas.

The injector-mixer 10 is positioned and designed to inject liquefied gas that is drawn off (and possibly sub-cooled) below the interface 18, so that the flow of liquefied gas mixes the liquefied gas contained in the tank 12.

The injection and the mixing of liquefied gas in the heel of a tank makes it possible to limit boil-off from the heel and to keep it cold for cooling before loading, without cooling the atmosphere in the tank. Keeping a cold liquid heel helps reduce excess gas at the start of loading.

The injection and the mixing of liquefied gas in a larger volume of a tank makes it possible to limit the risk of temperature stratification of the liquefied gas in the tank. It is preferable to ensure that the mixing kinetics and the orientation of the liquid flow make it possible to ensure sufficient mixing in the direction of the height of the tank. Indeed, the gas overhead naturally tends to stratify in temperature when there is less boil-off. That is, hot gas accumulates at the ceiling because it is lighter, which greatly reduces the heat flow coming from the outside. Cooling the atmosphere in the tank (via a return by means of spray bars) would therefore increase the heat flow and would therefore require the use of the higher capacity sub-cooling to compensate for the heat flow, which would represent a loss of energy and therefore of liquefied gas. If the gas overhead has stratified in temperature, cooling the atmosphere of the tank, via a return by spray bars, even if this LNG is sub-cooled, could result in increasing the tank pressure, because the dispersed LNG would boil off upon cooling the insulation of the heated tank. It is once the insulation has cooled that the injection of sub-cooled LNG would make it possible to control or even lower the tank pressure. The injection and the mixing of liquefied gas in the heel of a tank would therefore make it possible to control/lower the tank pressure instantly, even in the case where the gas overhead has warmed up.

Advantageously, the injector-mixer 10 is configured to inject a flow of liquefied gas in a direction which slopes upward at an angle α relative to a horizontal plane (Fig. 6). The angle α is for example between 5° and 85°, preferably between 15° and 75°, and more preferably between 30° and 60°.

As seen in Fig. 4, 6, 21 to 24, 30 and 31 which illustrate tanks where the injection device is positioned at the bottom of the tank, it is preferable to control

the angle α so that the mixing device is used in the ballast case (Fig. 4, 23 and 24 and 30) as well as in the laden case (Fig. 21, 22 and 30).

- In the ballast case (tank almost empty), this configuration makes it possible to stir the liquid over the majority of the length of the tank (great distance via a sufficiently low angle, that is to say close to the horizontal). Too great an angle (i.e. close to the vertical) could disperse the liquid in the gaseous gap, which would cool the gas and therefore increase heat transfers. When subcooling means 22 are used, too great an angle would also generate an accumulation of the injected liquid close to the injector and the draw-off means and would enable a the injected liquid to be drawn off again toward the subcooling means; there is a risk of the sub-cooled liquid being frozen.

- In the laden case (tank almost full), a sufficiently large angle (that is to say close to the vertical) allows the liquid to be stirred over most of the height of the tank, so that the temperature of the liquid is homogeneous over the entire height of the liquid, and thus makes it possible to avoid the formation of a hot liquid layer on the surface. Too small an angle (that is to say close to the horizontal) would not make it possible to reach the liquid surface where the hot liquid layer is formed. When subcooling means are used, too small an angle would generate an accumulation of the injected liquid at the bottom of the tank and close to the draw-off means and would enable a the injected liquid to be drawn off again toward the subcooling means; there is a risk of the sub-cooled liquid being frozen. There is also the risk of suddenly depressurizing the tank in the event of homogenization of the sub-cooled liquid which would have accumulated at the bottom of the tank, with possible opening of the safety valves if the pressure drops below atmosphere.

Still in the case of Fig. 4, 6, 21 to 24, 30 and 31, the injected flow can advantageously be controlled as a function of the height of liquid in the tank. In an almost empty tank, the flow rate can be reduced so as to limit the power consumed by the draw-off means and not to disperse the liquid in the gaseous gap (which would cool the gas and therefore increase heat transfers). The flow rate can be increased so as to stir the liquid over most of the height of the tank, in order to reach the surface and thus avoid the formation of a hot liquid layer

on the surface. This flow rate control can be carried out in several ways, for example by a speed variator of the draw-off means or by a set of control valves.

This makes it possible to facilitate the mixing of the liquefied gas in the tank, over substantially the entire height of the liquefied gas and over the greatest possible distance, as is schematically shown by the arrows in Fig. 4.

The tank 12 has a general parallelepipedal and elongated shape, and can also be chamfered, as shown in Fig. 4 and 5. The tank 12 comprises a rear longitudinal end 12a and a front longitudinal end 12b.

In the illustrated example, the pump 20 and the injector-mixer 10 are located at the rear end 12a of the tank 12. They can be located substantially perpendicular to the liquid dome of the tank. In this case, the pump 20 and the injector-mixer 10 can be connected to vertical pipes of the pump tower. These pipes can then support the injector 10.

As mentioned in the foregoing, the injector-mixer 10 is positioned so that it can result in a mixture of an optimal volume of liquefied gas in the tank. The power of the injector-mixer, that is to say the flow rate of liquid flow that it can deliver, depends in particular on the power of the pump 20. Advantageously, this pump is the one already fitted to the tank and in particular the pump tower and therefore has a limited power, for example less than or equal to 100 m^3/h, and for example less than or equal to 60 m^3/h.

The pump could be of the type with variable speed and therefore variable flow. This makes it possible in particular to adapt the power of the pump, and therefore the flow rate of the liquid flow injected by the injector-mixer, to the volume of liquefied gas in the tank and therefore to the filling level of the tank.

To remedy this and allow mixing of the total volume of liquefied gas in the tank, it is possible to equip the tank with several injector-mixers 10, as illustrated in Fig. 13 and described in the foregoing.

As can be seen in Fig. 21 to 24, which illustrate all-fill or restricted fill tanks, it is best to control the angle α so as to mix the maximum of liquefied gas in the tank. If the angle α is too low and the injectors-mixers inject liquefied gas directly toward the bottom wall, there is a risk of not mixing all of the liquefied

gas in the tank. Downward-facing injectors-mixers can be combined in the same tank with upward-facing injectors-mixers (Fig. 11-13 and 24).

Injectors-mixers having different orientations can thus be associated with one another so that the entire volume of liquefied gas stored in a tank is effectively mixed and therefore impacted by the liquefied gas injected into the tank.

The orientations and the number of the injectors-mixers 10 are therefore chosen so as to promote good mixing of the liquefied gas in the tank, to limit the recirculation of sub-cooled liquefied gas toward the pump, and slightly upward so as to limit the accumulation of sub-cooled gas, which is heavier (temperature stratification of the liquid if the tank is full). The injection as close as possible to the bottom of the tank allows the injected liquefied gas to remain in the liquid with a low filling level, to limit the cooling of the gas overhead as much as possible (at worst, the injection will cause a deformation of the free surface of the liquefied gas at the interface), and not to suck in gas by the Venturi effect, for example.

The devices of Fig. 21 to 24 show that the liquid draw-off means (pump 20) can be connected to the injectors-mixers 10 by pipes 34, and the assembly (including the pipes 34) is located inside the tank, which avoids having wall penetrations which are likely to cause sealing problems.

The pipes extend at least partly substantially parallel to and near the bottom wall of the tank, and preferably up to at least one side wall of this tank. In the case illustrated in the drawings where the pump is located in the center and at the bottom of the tank, the pipes may extend in opposite directions along the bottom wall and up to the side walls of the tank. The pipes can be configured to match the specific shape of the tank bottom and in particular that of the connecting chamfers between the bottom and side walls of the tank.

In the variant embodiment of Fig. 25, an injector(s)-mixer(s) bar in the upper part of the tank is combined with another bar in the lower part so that they can work together. The one in the upper part discharges the surface liquid in order to prevent a hot liquid layer from forming on the surface toward the injectors positioned at the bottom of the tank. The liquid which is sucked in is

that which is in contact with the vertical wall so as to send it back to the first row of injectors. This forced circulation of the liquid around the vertical walls and the surface makes it possible to prevent the formation of a liquid layer (because the liquid surface layer consists of LNG heated through the vertical walls).

In the variant embodiment of Fig. 26, an injector(s)-mixer(s) bar in the upper part of the tank is combined with another bar in the lower part so that they can work together. The one in the upper part discharges the surface liquid toward the bottom in order to prevent a hot liquid layer from forming on the surface toward the injectors positioned at the bottom of the tank. This forced circulation of the liquid around the vertical walls and the surface makes it possible to prevent the formation of a liquid layer (because the liquid surface layer consists of LNG heated through the vertical walls). Indeed, the angle of the ejectors makes it possible to effectively renew the liquid in contact with the vertical walls.

As mentioned in the foregoing, the two aspects of the invention can be combined so that the same tank can be equipped with several injectors-mixers, so some are oriented upward and others downward. In addition, the injectors-mixers may be oriented more to the right or more to the left, that is to say more toward the front or more toward the rear of the ship in the case where the injectors-mixers are located on the longitudinal sides of the ship. Several positioning and orientation configurations of the injectors-mixers of a tank are thus possible.

Fig. 1, 11-12 and 14 to 26 illustrate another advantage of the invention.

The injectors-mixers 10, and possibly the pumps 20, are positioned relative to one another and configured so as to generate both suction effects in the tank and back pressure effects in the tank. These suction and back pressure effects cause a predetermined stirring cycle of the liquefied gas in the tank, which is illustrated by the arrows forming closed loops.

The injectors-mixers 10 can on their own generate a back pressure effect by injecting liquefied gas and a suction effect due to the vacuum created in the injection zone. It will also be understood that the pumps 20 can generate a suction effect.

The stirring cycle is advantageously designed so that liquefied gas circulates substantially parallel to the liquid-gas interface in the tank, and close to this interface. This makes it possible to limit the risk of a hot liquid layer forming at the interface, and therefore of boil-off of the liquefied gas.

The natural convective movements of liquefied gas, due to temperature variations of the liquefied gas in the tank, complete this stirring cycle. This is for example the case of very cold liquefied gas, which is heavier than the hotter liquefied gas, the latter having a tendency to rise toward the liquid-gas interface in the tank. This liquefied gas can rise, for example, along the side walls of the tank, in particular when a brazing cycle takes place in the center of the tank.

In Fig. 11 and 12, the injection downward and at the side walls of the tank directly causes the discharge of liquefied gas downward along these walls, and indirectly (by induced effect) causes the suction of liquefied gas from the center of the tank toward the walls and in particular toward the injectors-mixers.

The observed effects are the reverse in Fig. 14. The injection upward and at the side walls of the tank directly causes the discharge of liquefied gas upward, and indirectly causes the suction of liquefied gas from the center of the tank toward the walls and in particular toward the injectors-mixers.

In the case of Fig. 15 and 16, the injectors-mixers located on one side of the tank, on the left in the drawings, are oriented upward and deliver liquefied gas to the injectors-mixers located on the opposite side, which are oriented downward and deliver liquefied gas to the other injectors-mixers. The discharge of liquefied gas at the outlet of the injectors-mixers creates depressions at the injectors-mixers which attract the liquefied gas discharged by the other injectors-mixers, hence the concept of a closed loop and therefore of a stirring cycle.

As can be seen in Fig. 21 to 26, the stirring cycles induced by the injectors-mixers located on one side of the tank may be symmetrical or different

from those generated by the injectors-mixers located on the other side of the tank. In these figures where the pump 20 is submerged, it itself generates a suction effect in the tank which actively participates in creating the stirring cycle. The pump can be located in the center of the tank and generate a suction effect which, combined with the back pressure effects of the injectors-mixers located on the sides of the tank, can induce a single stirring cycle in the tank (Fig. 22 and 24-26) or separate stirring cycles on both sides of the tank (Fig. 21 and 23).

Fig. 27 and 28 show a particular example of an injector-mixer 10. This injector-mixer 10 comprises a main pipe 40 for passage of a main jet 42 of liquid, and a secondary pipe 44 coaxial with the main pipe 40 for the forced passage of a secondary jet 46 of liquid by the Venturi effect at the outlet of the main pipe 40. The jets 42, 46 then mix in the secondary pipe 44 and these jets will then mix with the liquefied gas 48 into which they are injected, at the outlet of the secondary pipe 44.

An example of the relationship between the flow rates of the different jets is:

- o main jet 42 = 1 part, for example 25 m^3/h,
- o secondary jet 46 = 3 parts, for example 75 m^3/h,
- o mix of jets 42 and 46 = 4 parts, for example 100 m^3/h,
- o liquefied gas drive flow rate 48 = 12 to 80 parts.

This example shows the efficiency of an injector-mixer with a Venturi effect, which allows a fourfold dilution of the flow rate of sub-cooled liquid (without considering the induced flow). It further already allows mixing of the sub-cooled liquefied gas and limits the risk of accumulation (stratification) in the lower part of the tank, and the greater drive effect with a fluid that is less dense and less viscous fluid than water.

Using a variable flow pump or a more powerful pump, as mentioned in the foregoing, would make it possible to increase the flow rate of the main jet as well as the unloading speed and therefore the range of the jet. Nevertheless, it would be counterproductive to increase this flow excessively because a more powerful pump would generate more heat, which would increase the boil-off in the tank (yet for example, the purpose of the sub-cooler is to cool). Each bar of

pressure drop between the main jet and the secondary jet can for example increase the range of the jet by about five meters.

Fig. 29 illustrates and summarizes several examples of application of the different aspects of the invention.

A- The right part of the drawing illustrates the cases for which there is no cooling and/or recondensation means between the draw-off means (pump) and the injection means (injector-mixer):

A-1- When the tank is of the restricted fill type (LNGC type):

This concept is particularly relevant for storage of LNG carriers because intermediate fillings are not authorized (10% to 70% not authorized). What is more, the phenomenon of formation of the hot liquid layer with low filling (heel) is unlikely, therefore a heel mixing system is less efficient.

The invention therefore consists of one or more injector-mixer bars located in the liquid as close as possible to the liquid-gas interface.

The injectors-mixers are at the top of the tank, in the liquid, close to the interface because the objective is to renew the hot liquid layer at the interface. This positioning is therefore the most effective for reaching the surface given the high tank height (up to 27 m on LNG carriers).

Considering the hot liquid layer at the surface and the heat flows coming from the vertical walls, a distribution and an orientation of the injectors-mixers can make it possible not to mix the core of the liquid and therefore to reduce the mixing power (because they do not participate in the formation of the hot liquid layer), as in the above.

Given this positioning of the injectors-mixers (close to the surface), the pump can be of the variable flow type in order to reduce the power and therefore the heat input generated by the mixing (and therefore to increase the pressure rise time).

A-2- When the tank is of the all-fill type (LFS, FSRU, GBS, RT, LBV type):

The device comprises injectors-mixers positioned at the bottom of the tank and oriented upward. The pump is ideally controlled so that the flow rate and supply pressure of the injectors-mixers are adapted as the surface approaches the mixers (i.e. the LNG level drops in the tank). This makes it possible to limit the cooling of the gas overhead and to avoid spraying the gas because of an overly powerful jet. What is more, if the pump is variably controlled, this control will increase the pressure rise time and reduce the heating of the pump.

Particularly for passenger ships, the device can be “self-contained” without any pipes protruding outside the tank. In fact, in the event of damage (example of SOLAS SRTP = *Safe Return To Port* constraints and IGF code), the tank must be automatically isolated (all of the valves at the crossings are therefore automatically closed). The time for the pressure rise should preferably be long enough to allow the ship and its passengers to return to port without degassing the tank (SRTP constraint) or be greater than 15 days (IGF code constraint).

B- The left part of the drawing illustrates the cases for which there are cooling and/or recondensation means between the draw-off means (pump) and the injection means (injector-mixer):

In each of the concepts below, the key principle sought is to be able to reinject the cold power (transported by the sub-cooled LNG) into the liquid and not into the gas overhead.

In fact, reinjecting the majority of the cold power into the gas overhead will first result in a significant drop in pressure due to the cooling of the gas overhead, then the cooling of the insulating bulk of the tank will cause the dispersed LNG to boil off, which will increase the pressure significantly during the cooling time. Finally, the cooling of the gas overhead will force the heat flow entering the upper part of the tank and therefore a significant part of the LNG reinjected into the gas overhead will then be unnecessarily vaporized, which would limit the cold power supplied to the liquid. This is especially true

inasmuch as this will be distributed only to the free surface of the liquid, which would cause the diffusion kinetics to be slow.

On the contrary, the invention proposes to reinject the cold power directly into the liquid below the free surface in order to reduce the influence on the temperature and the pressure of the gas overhead. In addition, injecting below the free surface will create a mixing and stirring effect by adjusting the kinetics of the liquid at the outlet of the return line, its orientation, its elevation, etc.

For these cases, it is not necessarily required to distribute the injectors-mixers in a homogeneous manner in the tank because the aim is simply to dilute the injected liquid with the liquid which is already present (and not to reach the liquid-gas interface).

B-1- When the tank is full:

The tank is loaded (after loading and before unloading). The injection and mixing at the top of the tank promotes good mixing of the sub-cooled LNG with the stored LNG. Indeed, the injected LNG is colder and therefore heavier than the surrounding LNG, which justifies the positioning in the upper part of the tank slightly below the surface and oriented slightly downward with a relatively low angle α so as to mix the front of the tank as much as possible. As a variant or additional feature, the injection of LNG could take place by means of the spray bars, therefore in the gas overhead.

B-2- When the tank is empty or partially filled:

When the tank is empty (ballast trip before loading) or at an intermediate fill level. The injection and the mixing make it possible to cut boil-off from the heel and to keep it cold for cooling before loading, without cooling the atmosphere in the tank.

When the tank is partially loaded (after loading and before unloading), there is a risk of temperature stratification of the cold LNG. It will be necessary to ensure that the mixing kinetics and the orientation of the liquid flow make it possible to ensure sufficient mixing in the direction of the height of the tank.

The gas overhead naturally tends to stratify in temperature when there is less boil-off. That is, hot gas accumulates at the tank ceiling because it is

lighter, which greatly reduces the heat flow coming from the outside. Cooling the atmosphere in the tank (via the spray bars) would therefore increase the heat flow and would therefore require using the higher capacity sub-cooling means to compensate for the flow, which would generate losses of energy and therefore of LNG. Simply dumping LNG at the bottom of the tank, without mixing, risks causing the sub-cooled LNG to be sucked in, which would require stopping the sub-cooling means. Cooling the cold liquid heel helps reduce excess gas at the start of loading.

When the tank is almost empty and in combination with sub-cooling means 22, it is preferable to inject the liquid at the tank bottom directly into the heel for the reasons mentioned above. However, this injection system at the tank bottom can also be used when the tank is full (or almost full) in the case where the angle α of the injectors is chosen appropriately. As seen in Fig. 4, 6, 21 to 24, 30 and 31, which illustrate tanks where the injection means are positioned at the tank bottom, it is preferable to control the angle so that these means of injection and therefore mixing can be used in the ballast case (Fig. 4, 23 and 24, and 30) as well as in the laden case (Fig. 21 and 22 and 31).

- In the ballast case (tank almost empty), this configuration makes it possible to stir the liquid over the majority of the length of the tank (great distance via a sufficiently low angle, that is to say close to the horizontal). Too large an angle (that is to say, close to the vertical) could disperse the liquid in the gaseous gap (which would cool the gas and therefore increase heat transfers). When subcooling means 22 are used, too great an angle would also generate an accumulation of the injected liquid close to the injector and the draw-off means and would enable the injected liquid to be drawn off again toward the subcooling means; there is a risk of the sub-cooled liquid being frozen.

- In the laden case (tank almost full), a sufficiently large angle (that is to say, close to the vertical) allows the liquid to be stirred over most of the height of the tank, so that the temperature of the liquid is homogeneous over the entire height of the liquid, and thus makes it possible to avoid the formation of a hot liquid layer on the surface. Too small an angle (that is to say, close to the horizontal) would not make it possible to reach the liquid surface where the hot

liquid layer is formed. When a subcooling means is used, too small an angle would generate an accumulation of the injected liquid at the bottom of the tank and close to the draw-off means and would enable the injected liquid to be drawn off again toward the subcooling means; there is a risk of the sub-cooled liquid being frozen. There is also the risk of suddenly depressurizing the tank in the event of homogenization of the sub-cooled liquid which would have accumulated at the bottom of the tank, with possible opening of the safety valves if the pressure drops below atmosphere.

CLAIMS

1. Liquefied gas storage device, in particular for a liquefied gas carrier or for a land-based facility, comprising:

- at least one liquefied gas storage tank (12) that has a tank bottom (14) and a tank ceiling (16) which together define a tank height (H),
- means (20) for drawing off gas, in liquid and/or gaseous form, in said tank, and
- means (10) for injecting gas in liquid form into said tank, which means are connected to the gas draw-off means,

characterized in that said gas injection means comprise at least one injector-mixer (10) which is located in a lower zone of said tank extending between 0 and 25% of the tank height measured from said tank bottom, and which is intended to be immersed in said liquefied gas contained in the tank, wherein said injector-mixer (10) comprises a main pipe (40) for passage of a main jet (42) of liquid, and a secondary pipe (44) for forced passage of a secondary jet (46) of liquid by the Venturi effect.

2. The device according to the preceding claim, wherein said at least one injector-mixer (10) is configured to inject a flow of liquid gas in a direction which is inclined upwardly at an angle α relative to a horizontal plane.

3. Device according to the preceding claim, wherein said angle α is between 5° and 85°, preferably between 15° and 75°, and more preferably between 30° and 60°.

4. Device according to one of the preceding claims, wherein said at least one injector-mixer (10) is located at a distance of less than one meter to a longitudinal side wall (12c) of said tank.

5. Device according to one of the preceding claims, wherein said injection means comprise at least one horizontal row of injectors-mixers (10) which are configured to inject flows of liquid gas in parallel or different directions.

6. Device according to one of the preceding claims, wherein said injection means comprise at least two horizontal rows of injectors-mixers (10) which are

arranged respectively on and/or along two longitudinal side walls (12c) of said tank.

7. Device according to one of the preceding claims, wherein said gas injection means (10) are connected by reliquefaction means (22) to means for drawing off gas in said tank or in another tank.

8. Device according to the preceding claim, wherein said reliquefaction means (22) are configured to recondense boil-off gas drawn off from said tank or from another tank and then pressurized, by heat exchange with liquefied gas drawn off from said tank or from another tank.

9. Device according to one of claims 1 to 4, wherein said gas injection means (10) are connected by sub-cooling means (22) to means (20) for drawing off liquid gas from said tank or from another liquefied gas storage tank.

10. Device according to one of the preceding claims, wherein said draw-off means (20) are configured to draw off liquid gas from said lower zone.

11. Device according to one of the preceding claims, wherein said draw-off means comprise at least one pump (20) located in said tank (12) or in another tank and intended to be submerged in said liquefied gas.

12. Device according to the preceding claim, wherein said pump (20) is configured to have a variable flow rate.

13. Device according to one of the preceding claims, wherein said tank (12) is of the “all-fill” type and is configured to be filled to any level.

14. Device according to one of the preceding claims, wherein said draw-off means (20) and said injection means (10) are located in said tank (12) and connected to each other by pipes (34) located entirely in the tank.

15. Device according to the preceding claim, wherein said draw-off means (20) and said injection means (10) are located perpendicular to a liquid dome (LD) of said tank (12), and preferably equip a pump tower which is accessible by this liquid dome.

16. Device according to the preceding claim, wherein said at least one injector-mixer (10) is connected to a liquid column of said pump tower, and is supported by this column.

17. Device according to one of the preceding claims, wherein said injection means (10) and said draw-off means (20) are positioned relative to one another and configured so that they generate back pressure and suction effects in the tank, these effects generating a predetermined stirring cycle of the liquefied gas in the tank.

18. Liquefied gas carrier, comprising at least one liquefied gas storage device according to one of the preceding claims, this device being devoid of sub-cooling and reliquefaction means between said draw-off and injection means, said tank being of the “all-fill” type and being configured to be filled to any level.

19. Liquefied gas carrier, comprising at least one liquefied gas storage device according to one of claims 1 to 17, this device comprising means for sub-cooling and/or reliquefaction between said draw-off and injection means, said tank being of the “all-fill” and/or “restricted fill” type.

20. Method of injecting gas in liquid form into a tank of the Liquified gas carrier according to claim 18 or 19.

21. Method according to claim 20, wherein said tank is of “restricted fill” type and the injection takes place when the tank is filled to a volume of 10% and less.

22. Method according to claim 20, wherein the injection takes place when the “all-fill” tank has any level of filling, the injection angle being identical irrespective of this level and the injection rate being controlled according to this level.

23. Method according to the preceding claim, wherein the greater the volume of liquid in the tank, the greater the injection rate.

24. Method according to one of claims 20 to 23, wherein the injected liquefied gas has a temperature lower than that of the liquefied gas contained in said tank.

25. Method according to one of claims 20 to 24, wherein said injection means (10), or even also said draw-off means (20), are controlled so that they generate back pressure and suction effects in the tank, these effects generating a predetermined stirring cycle of the liquefied gas in the tank.

26. Method according to the preceding claim, wherein the stirring cycle is designed so that liquefied gas circulates substantially parallel to the liquid-gas interface (18) in the tank, and close to this interface.