

Device and method for cooling liquefied gas and/or natural boil-off gas from liquefied gas

TECHNICAL FIELD

5 The invention concerns a device and method for cooling liquefied gas and/or natural boil-off gas from liquefied gas for an energy production installation, in particular on board a ship, such as a ship for transporting liquefied gas or machinery of which uses liquefied gas.

10 PRIOR ART

The prior art includes in particular the document EP-A1 2 670 274.

In order to transport gas, such as natural gas, more easily over long distances the gas is generally liquefied (to become liquefied natural gas – LNG) by cooling it to cryogenic temperatures, for example -163°C at atmospheric
15 pressure. The liquefied gas is then loaded into specialized ships.

In a ship for transporting liquefied gas, for example of the methane tanker type, an energy production installation is provided to provide for the energy requirements of the operation of the ship, in particular for the propulsion of the ship and/or the production of electricity for onboard equipment.

20 An installation of this kind routinely includes thermal machines consuming gas coming from an evaporator that is fed from the cargo of liquefied gas transported in the tank or tanks of the ship.

The document FR-A-2 837 783 provides for feeding an evaporator of this kind and/or other systems necessary for propulsion with the aid of a pump
25 immersed at the bottom of a tank of the ship.

In order to limit evaporation of the liquefied gas, it is known to store it under pressure in the tank so as to move along the liquid-vapor equilibrium curve of the liquefied gas concerned, thus increasing its evaporation temperature. The liquefied gas can therefore be stored at higher temperatures
30 the effect of which is to limit evaporation of the gas.

Natural evaporation of the gas is inevitable, however, this phenomenon being known as *natural boil-off gas* (NBOG), as against *forced boil-off gas*

(FBOG). The gas that evaporates naturally in the tank of a ship is generally used to feed the aforementioned installation. In the case (first case) in which the quantity of gas evaporated naturally is insufficient for the fuel gas demand of the installation, the pump submerged in the tank is actuated to supply more fuel gas following forced evaporation. In the case (second case) in which the quantity of gas evaporated is too great relative to the demand of the installation, the excess gas is generally burned in a gas combustion unit, which represents a loss of fuel gas.

In the current state of the art, tank improvements are such that the natural rates of evaporation (BOR – *Boil-Off Rate*) of the liquefied gases are lower and lower, whereas the machinery of a ship offers higher and higher performance. In each of the aforementioned first and second cases the consequence of this is that there is a very great difference between the quantity of gas naturally produced by evaporation and that demanded by a ship's installation of a ship.

Consequently, there exists a growing interest in solutions for cooling the liquefied gas contained in a storage tank and management of the BOG generated in that tank, such as reliquefaction or cooling units, for example, such as those described in the application WO-A1-2016/075399. The idea on which the present document is based is to propose a device for cooling a liquefied gas making it possible to limit natural boil-off of the liquefied gas whilst maintaining it in a thermodynamic state enabling its long-term storage. However, the heat exchanger technology described in the above document is costly and relatively ineffective, and has other disadvantages that will be described in detail hereinafter.

Moreover, a number of parameters influence the generation of NBOG, such as liquid movements and ambient conditions. The energy requirements in a ship also vary greatly, according to the operation being carried out and the speed at which it is sailing. Consequently, it can prove difficult to implement an effective BOG management solution because the excess quantity of NBOG can vary enormously.

The present invention proposes an improvement to the current state of the art that is simple, effective and economical.

STATEMENT OF INVENTION

5 According to a first aspect, the invention proposes a device for cooling liquefied gas, in particular for an energy production installation on board a ship, characterized in that it includes:

- optionally, a main liquefied gas storage tank,
- a first cooled liquefied gas separation drum, an inlet of which is connected to
10 a first end of a first pipe a second end of which is intended to be immersed in the liquefied gas contained in said main tank, preferably at the bottom of the tank, said first pipe being adapted to feed said first drum with liquefied gas,
- means for reducing the pressure in said first drum relative to said main tank, configured to apply in said first drum an operating pressure lower than the
15 pressure in said main tank,
- evaporation means equipping said first pipe and/or said inlet of said first drum so that at least some of the liquefied gas feeding said first drum, termed boil-off gas, is evaporated, and at least another portion (for example the remainder) of that liquefied gas, termed cooled liquefied gas, is cooled to the saturation
20 temperature at said operating pressure in said first drum, said first drum being configured to separate said evaporated gas and said cooled liquefied gas, and
- means for feeding said main tank with said cooled liquefied gas contained in said first drum in order to cool the gas that has been liquefied and/or is in gas form contained in said main tank.

25 Here it is the liquefied gas that is cooled, or rather further cooled, and intended to be used to cool and to control the temperature of the liquefied gas contained in the main tank.

 The first drum acts as a vacuum evaporator and is associated with the first compressor that acts as a vacuum evaporation compressor. It is known that
30 evaporation or depressurization of a gas releases frigorific energy. The evaporation means may therefore be regarded as cooling means. Moreover, the terms evaporation means, pressure reduction means and depressurization

means have similar or even identical meanings in the context of the invention. According to the invention, evaporation means equip the first pipe and/or the inlet connecting that first pipe to the first drum. The first drum may further form (complementary) evaporation means, as explained hereinafter.

5 Thus the invention proposes to replace the prior art exchanger with a vacuum evaporator, which makes it possible to obtain a higher cooling power and therefore to improve the effectiveness of the cooling of the gas that has been liquefied and/or is in gas form contained in the main tank.

10 The main tank is optional in that it may be considered as forming part or not of the device according to the invention. The device may for example be shipped with no main tank, which therefore does not form part of the device. Alternatively, once mounted on a ship, for example, the device is associated with a main tank which therefore forms part of the device according to the invention.

15 It is advantageous if there is no heat exchanger (the disadvantage of which is to generate a loss of cooling by the pinch effect) operative during the expansion or evaporation step. In the prior art, using a heat exchanger of this kind, all of the light fraction is totally evaporated thanks in particular to the exchanger that evaporates the light fraction of the gas that has remained liquid
20 after depressurization. Depressurization and the exchanger are not sufficient also to evaporate the heavy fraction, however.

 In the present application there is meant by heavy fraction and light fraction, respectively, the heavy gases or gases with a high molar weight and the light gases or gases with a low molar weight. In one embodiment the
25 liquefied gas is liquefied natural gas. In this case a light gas is methane. In liquefied natural gas there may also be a small amount of nitrogen in the light fraction. The minority heavy fraction includes, for example, for the liquefied gas, propane, butane and ethane (which therefore evaporates at a higher temperature or at a pressure lower for example than the operating pressure). In
30 the liquefied gas, the heavy fractions represent between 5.2% and 49.8% of the total mass of liquefied gas. The heavy fractions have for example molar masses between 25 and 500% greater than those of the light fractions.

The improvements procured by this device are numerous and for example as follows:

- a simpler architecture, simpler control and more secure use thanks to a cooling process that can take place entirely outside the main tank,
- 5 - improved efficiency because of the suppression of the pinch effect that can occur with a prior art exchanger, such as that described in the application WO-A1-2016/075399; given the operating pressures and associated temperature drops, a pinch effect of 1 to 2°C represents around a 15% loss of cooling power,
- 10 - the cooling power is generated in the form of cooled liquefied gas that can be fed and used as required, or even stored for subsequent use; this is particularly advantageous since this power can be generated by recovering energy from forced boil-off gas during phases lacking NBOG corresponding to phases in which heating power is necessary rather than cooling power,
- 15 - a contrario, considering the typical dimensions of a main tank, in particular on a ship, the volume of gas stored in a tank of this kind and the sizes of the cooling equipment required as described in the aforementioned earlier application, the cooling power recovered with this equipment is not sufficient for its storage and subsequent use,
- 20 - the liquefied gas is intended to undergo phase separation in the drum, only the gas, which may be used in the installation, being intended to be aspirated by the pressure reducing means such as a compressor; there is therefore no risk of any droplet being aspirated by the compressor, which could damage it; considering the operating pressure ranges, the temperatures and compositions
- 25 of liquefied gas, in most cases the liquefied gas will not be completely evaporated in a heat exchanger such as that described in the aforementioned earlier application; for example, the ratio of liquid in the initial architecture at 120 mbara is between 0.12 and 32% inclusive and at 800 mbara (it is not possible to consider a pressure of 950 mbara as proposed in the earlier
- 30 application because of the pinch effect in the exchanger) it is between 0.8 and 92% inclusive (high variations because of different liquefied gas compositions),

- in the earlier application, all the flow necessary to feed the installation, that is to say intended for the consuming unit, has to pass through a compressor, which is not necessarily the case with the invention in which only the necessary quantity of forced boil-off gas is used to top up the quantity of natural boil-off gas produced; the capacity of the compressor is therefore reduced, which makes it possible to reduce the initial investment costs and the operating expenses; moreover, as each component of the device introduces losses, it is overall more effective to limit the flows circulating in the device; finally, the proposed device is easy to connect to a ship's conventional consumption installation, consequently limiting the impact on the existing environment and imparting more flexibility to the design of machines on a ship using the fuel gas;

- the drum is preferably located outside the main tank, facilitating the device and making it safe.

All in all, compared to the usual device installed on a ship in which additional BOG is generated by feeding a heat exchanger with liquefied gas by means of a pump, here the device reduces the total energy expenditure for evaporation by 31 to 38%. The main aim is to generate cold by recovering the evaporation energy that is typically an expenditure item on a ship. Depending on the characteristics of the ship, in particular the sailing speed profile, the efficiency of its machinery, etc., the device makes it possible to generate a cooling power up to 175% of the heat produced during a voyage of the ship (including the return trip including commercial use and awaiting entry into a waterway).

The pressure in the main tank may vary according to the depth in the tank because of the hydrostatic pressure.

In the context of the present invention by the "bottom" of a tank is meant a position situated less than one meter from a bottom wall of the tank, that bottom wall being the wall of the tank that in operation is closest to the center of the earth. The or each pump is preferably also as close to the bottom as possible to function up to the lowest possible filling level (the distance from the bottom is limited by the fact that a pump too close to the bottom may be difficult to prime).

The device according to the invention may have one or more of the following features, separately from one another or in combination with one another:

- said first drum is a separation and/or expansion drum;
- 5 - at least a part of said first drum and/or at least a part of said first pipe and/or at least a part of said evaporation means is or are housed or intended to be housed in said main tank;
- said first drum is configured to be fed only with liquefied gas;
- the pressure of the liquefied gas in said first pipe is preferably greater
- 10 than the hydrostatic pressure generated by the submerged portion of that first pipe in said main tank;
- the diameter of said first pipe ahead of said depressurization means is preferably as small as possible to limit cooling of the liquefied gas in that pipe (cold loss limit);
- 15 - said first pipe is preferably configured so that the liquefied gas taken up in said main tank remains liquid as far as said depressurization means; although the pressure falls in the first pipe because of the hydrostatic pressure because of the reduced depth of immersion in the main tank, the pressure remains sufficiently high for all the gas to remain liquid;
- 20 - the pressure in the first pipe at the inlet of the depressurization means is for example approximately 1 bar; the liquefied gas having been only slightly heated in the first pipe, it still remains at a temperature at which it is liquid at approximately 1 bar (for example at approximately -160°C);
- said evaporation means include a valve, for example a JT or Joule-
- 25 Thomson valve, and/or a portion of the first pipe situated in particular downstream of the valve;
- the liquefied gas taken up is preferably evaporated (for the most part or more than 80%, even 90%) just after the valve, in said first pipe portion; the liquefied gas is also cooled in this pipe portion because of the pressure
- 30 reduction by the "flash" evaporation effect (spontaneous pressure reduction);

- this pipe portion may have a larger diameter than the first pipe portion situated ahead of the valve, in particular so as to have a sufficient flow rate, because the boil-off gas occupies a greater volume;
- alternatively, evaporation may take place for the most part or even only 5 (more than 80%) in said first drum, if the pipe portion between the valve and the first drum is reduced or absent; in this case, unless the first drum is of sufficient volume, there may not be continuous operation; it would therefore be necessary to wait for the liquefied gas evaporation and cooling phenomenon to come to an end, at a temperature just below the boiling point at the new pressure, following 10 ("flash") pressure reduction to empty the first drum, in particular into the secondary tank mentioned hereinafter; it would moreover be possible in this case in particular to replace the valve, for example the JT valve, with a simple two-state valve (all or nothing, that is to say 100% closed/100% open);
- said pressure reduction means include at least a first compressor an inlet 15 of which is connected to a first gas outlet of said first drum and an outlet of which is able to supply fuel gas, in particular to said installation, said first compressor being able to aspirate at least some of said gas evaporated in said first drum and to apply said operating pressure in said first drum; instead of this or in addition to this, the pressure reduction means include at least one pump 20 an inlet of which is connected to a liquid outlet of said first drum; in this variant, at least one compressor could be used to aspirate the evaporated gas contained in said first drum;
- said supply means include a second pipe a first end of which is connected to a second cooled liquefied gas outlet of said first drum and at least 25 one second end of which is intended to discharge into said main tank, said second pipe being able to inject at least some of said cooled liquefied gas from said second drum into said main tank; the connection of the first drum to said main tank, by means of said second pipe, may be direct or indirect; in other words, the second pipe may include or be associated with other fluidic 30 communication components or divided into sections between which such components are disposed; this may be the case of all the pipes referred to in the context of the invention;

- gas in liquid and/or gas form may be injected into said main tank, in particular by means of said second pipe; a mixture of gas and vapor may be injected into the main tank; if that mixture is reinjected at the bottom of the tank, the gas part of the mixture will tend to recondense because of the hydrostatic pressure of the gas and the temperature of the liquefied natural gas in the main tank; this can slow down the reduction of pressure in the main tank;
- the device includes a first pump connected to said second end of said first pipe and intended to be submerged in said liquefied gas contained in said main tank, preferably at the bottom of the tank, so as to force circulation of liquefied gas through said first pipe to said first drum; alternatively, the device has no such first pump; this is for example the case if the first drum and the first pipe are inside said first tank;
- the device includes a second pump connected to said second pipe so as to force circulation of at least some of said cooled liquefied gas through said second pipe from said first drum to said main tank; alternatively, this second pump would not be necessary, for example in the case of discontinuous operation where the first drum would be fed with liquefied gas up to a predetermined filling level, and would then have its pressure reduced to cause cooling of the liquefied gas and partial evaporation, which would lead to a rise in pressure in said first drum to a value substantially close to the pressure in the main tank, sufficient to render the second pump optional;
- the first pipe is equipped with an all or nothing valve and adapted to be closed for example when a reduced pressure is created in said first drum;
- the first or the second pump may be a fuel pump or a drier pump equipping the ship; this type of pump is typically able to provide a maximum flow rate of the order of 25-30 t/h; alternatively, a pump with a higher maximum flow rate may be used, in particular as the first pump, which would for example be able to provide a maximum flow rate of 300 t/h, or preferably even up to 2500 t/h;
- the system formed by the first drum, the first compressor and the first pump acts as vacuum evaporation means (or as a vacuum evaporator);

generally speaking, in the case of the present invention the system formed by a drum, a compressor and a pump is similar to vacuum evaporation means;

- the evaporation means are preferably configured to lower the pressure of the gas to the operating pressure of the first drum;
- 5 - said second outlet of said first compressor is connected to an inlet of a second compressor an outlet of which is able to supply said installation with fuel gas;
- said second pipe includes or is connected to a dip tube intended to be immersed in the liquefied gas contained in said main tank and/or a spray manifold in said main tank in order to inject cooled liquefied gas into said main tank; cooled liquefied gas can therefore be injected into the gas and/or into the liquefied gas contained in the main tank;
- 10 - said second outlet of said first drum is connected to a first inlet of a secondary tank so as to feed that tank with cooled liquefied gas and to store the cooled liquefied gas in that tank;
- 15 - the secondary tank is configured to contain said cooled liquefied gas at a pressure higher than said operating pressure in said first drum; the secondary tank is therefore at a higher pressure than the first drum, for example at atmospheric pressure; the secondary tank can therefore be less costly in that it can be designed to store a high volume of gas; this is an advantage of this secondary tank; the cooled gas can therefore accumulate in the first drum if the requirements of the installation are greater than the natural evaporation, and then decanted into the main tank so as to slow the natural boil-off if the requirements of the installation are less than the natural evaporation;
- 20 - the cooled liquefied gas contained in said secondary tank may be regarded as sub-cooled liquefied gas; "sub-cooled" means that the gas is at a temperature strictly lower than the boiling point (that is to say the saturation temperature) at the pressure to which the gas is subjected; in the secondary tank, the liquefied gas is at a pressure such that it may be considered sub-cooled;
- 25 - the secondary tank acts as a fluid, in particular BOG, cooling heat exchanger;
- 30

- said second pump is situated between said second outlet of said first drum and said first inlet of said secondary tank;
- said secondary tank includes a first outlet for at least some of said cooled liquefied gas connected to said second pipe, said second pipe being able to
5 route at least some of said cooled liquefied gas from said secondary tank to said main tank;
- said device includes at least one heat exchange circuit configured to cool a fluid circulating in said circuit using at least some of the cooled liquefied gas stored in said secondary tank or coming from said secondary tank; this heat
10 exchange circuit may be situated in the secondary tank, adjacent to or associated with the secondary tank, or spaced from that secondary tank; a cooled liquefied gas pipe may for example be used to feed said heat exchange circuit, which may form part of a separate heat exchanger; alternatively, the cooled liquefied gas used to cool the fluid circulated in said heat exchange
15 circuit could come from another source, such as the main tank or the first drum for example;
- combining said secondary tank and said heat exchange circuit enables reprocessing of the natural boil-off gas with very high efficiency since the pinch effect relating to the exchanger is small compared to the temperature difference
20 between the natural boil-off gas (the gas in the vapor phase at the inlet of the secondary tank at a temperature for example between -80°C and -160°C inclusive for example or more precisely between -100 and -140°C inclusive) and the liquefied gas, in particular thanks to the fact that the liquefied gas is cooled; of course, in the absence of a secondary tank the same advantage could be
25 obtained by an exchange with the cooled gas from said first drum or from the main tank; in other words, cooled liquefied gas may be stored in the secondary tank, the first drum and/or the main tank;
- said heat exchange circuit includes an inlet connected to a natural boil-off gas outlet of said main tank; in this context, said heat exchange circuit can
30 enable reprocessing of the natural boil-off gas in the main tank with very high efficiency since the pinch effect relating to the exchanger would be small

compared to the temperature difference between the natural boil-off gas and the liquefied gas, thanks in particular to the fact that the liquefied gas is cooled;

- said inlet of said circuit is connected to said outlet of at least one compressor, such as said first or second compressor, which is fed with natural boil-off gas coming from said outlet of said main tank; the natural boil-off gas is therefore compressed (which increases its temperature) before entering the exchanger or the exchange circuit with the cooled liquefied gas;
- said inlet of said circuit is connected to said outlet of at least one compressor, such as said first or second compressor, by a primary circuit of a first heat exchanger, said first heat exchanger including a secondary circuit an inlet of which is connected to said natural boil-off gas outlet of said main tank and an outlet of which is connected to said inlet of said first or second compressor; the natural boil-off gas taken up in the main tank will be heated when it enters said secondary circuit, which is not a problem in that it has to be heated anyway if it is used to feed the installation; an exchange advantageously takes place beforehand (the exchange must take place beforehand since the natural boil-off gas is less cold than the cooled liquefied gas) between all of the natural boil-off gas (including a portion feeding the installation) and a compressed portion of that natural boil-off gas (the surplus above and beyond the consumption of the installation that is recondensed);
- said heat exchange circuit includes an outlet connected to an inlet of a second drum, said second drum including a first cooled liquefied gas inlet connected to said second pipe in order to inject cooled liquefied gas into said main tank; alternatively, the device could be configured to reinject into the main tank, for example at the bottom of the tank, a gaseous part of the mixture, which would tend to recondense because of the hydrostatic pressure of the gas and the temperature of the liquefied gas in the main tank;
- said second drum is a drum and/or phase separation drum;
- said outlet of said circuit is connected to said inlet of said second drum by a valve, such as a Joule-Thomson (JT) effect valve, in order to reduce the temperature of the gas through adiabatic expansion; the natural boil-off gas can therefore be expanded; the compression/pressure reduction on either side of

the exchanger or of the heat exchange circuit can enable a lower temperature of the natural boil-off gas to be obtained, and therefore more natural boil-off gas to be condensed;

- the device includes a second heat exchanger a primary circuit of which
5 has an inlet connected to an outlet of a third pump intended to be immersed in the liquefied gas in said main tank and a cooled liquefied gas outlet, and a secondary circuit has an inlet connected to said first pipe and an output connected to the inlet of said first drum;
- said second heat exchanger is not immersed in the liquefied gas in said
10 main tank or mounted in said main tank;
- the outlet of the primary circuit of said second heat exchanger is connected to an inlet of said secondary tank in order to feed said secondary tank with cooled liquefied gas;
- the device has no components other than pumps and/or pipes immersed
15 in the liquefied gas contained in said main tank;
- said liquefied gas includes at least a so-called pure fraction including a pure gas or body and said cooled liquefied gas and said boil-off gas include said at least one pure fraction. If the liquefied gas is liquefied natural gas, a pure fraction of this kind may consist of methane.

20 In the present application, by "pure" is meant a single body or a chemical species as opposed to a mixture of bodies or species. Said pure gas is for example a light gas or a heavy gas.

The present invention further concerns a ship, in particular for transporting liquefied gas, including at least one device as described
25 hereinabove.

The present invention further concerns a method of cooling liquefied gas for an energy production installation, in particular on board a ship, by means of a device as described above, characterized in that it includes:

- a step A of taking up liquefied gas contained in said main tank, said
30 liquefied gas being taken up in said first pipe at a take-up temperature,
- a step B of expanding said taken up gas to an expansion pressure lower than a saturated vapor pressure of said gas taken up at said take-up

temperature so that a part of said taken up gas is evaporated because of the effect of the expansion, and so that a remaining part of said taken up gas remains liquid and is cooled to a temperature lower than that of said take-up temperature, in particular because said taken up gas is cooled to a saturation
5 temperature at said expansion pressure,

- a step C of filling said first drum with liquefied gas and in said drum separating, in particular by gravity, said evaporated gas and said cooled liquefied gas,

- a step D of supplying said installation with at least some of said
10 evaporated gas contained in said first drum, and

- a step E of cooling the liquefied gas contained in said main tank by means of cooled liquefied gas contained in said first drum in order to cool the gas contained in said main tank.

The saturated vapor pressure is the pressure at which the gas phase of
15 a substance is in equilibrium with its liquid or solid phase at a given temperature in a closed system.

According to the invention, instead of using pressure reduction and cooling in an evaporation enclosure and exchange of heat between that evaporation enclosure and the liquefied gas in a drum to cool the liquefied gas
20 decanted into the main tank, flash evaporation is used in the drum and the resulting cooled liquid is returned to the main tank. The advantage of this is primarily the suppression of the pinch effect of the exchange of heat between the evaporation enclosure and the liquefied gas from the drum.

According to one embodiment, the liquefied gas taken up consists of a
25 pure gas, for example methane. In this case, the liquefied gas circulating in said first pipe may consist of a mixture including that pure gas, for example liquefied natural gas including methane.

The method according to the invention may include one or more of the following steps or have one or more of the following features, separately from
30 one another or in combination with one another:

- the step E includes the injection of cooled liquefied gas into said main tank by circulating it in said second pipe in order to cool the liquefied gas contained in said main tank;
- the method includes a step of spraying droplets of cooled liquefied gas
5 into the gas contained in said main tank, that gas being situated above the level of the liquefied gas contained in the main tank,
- the method includes a step of compressing gas leaving said first outlet of said first drum;
- the pressure in said first drum is between 120 and 950 mbara inclusive
10 and/or the pressure in said main tank is between 20 and 700 mbarg inclusive, between 20 and 350 mbarg inclusive, or between 20 and 250 mbarg inclusive, in particular for a tank at atmospheric pressure, and is at a pressure up to 10 mbara for a pressurized tank, and/or the expansion leads to an evaporation fraction between 0.94 and 15.18% inclusive, and/or the flow rate in the first pipe
15 is between 18.09 and 374.7 t/h inclusive, and/or the production rate of cooled liquefied gas in said first drum is between 15.35 and 371.6 t/h inclusive, and/or the secondary tank has an internal volume or a capacity between 1312 and 86037 m³ inclusive, and/or the temperature of the cooled gas, after taking up liquefied gas or natural boil-off gas and cooling that gas, is between -159 and -
20 180.4° inclusive, and/or the evaporation of the compressed natural boil-off gas leads to an evaporation fraction between 81.63 and 100% inclusive;
- the method includes a step of preheating liquefied gas taken up in said main tank by exchange of heat with the fluid circulating in said primary circuit, after expansion and before injection of said liquefied gas which may be partly or
25 completely evaporated in said first drum;
- the method includes a step of precooling liquefied gas taken up in said main tank by exchange of heat with the fluid circulating in said secondary circuit before its injection into said secondary tank;
- the method includes a step of cooling gas leaving said first or second
30 compressor by exchange of heat with the cooled liquefied gas contained in said secondary tank;

- the method includes a step of precooling the gas leaving said first or second compressor before it is cooled in said secondary tank by exchange of heat with natural boil-off gas taken up in said main tank;
 - the method includes a step of preheating the natural boil-off gas taken up
5 in said main tank before its compression by said first or second compressor;
 - the method includes before filling said second drum a step of lowering the pressure and/or the temperature of the gas intended to feed said second drum;
 - the method includes a step of injecting cooled liquefied gas into said
10 main tank by means of said second pipe; this injection enables participation in cooling the liquefied gas contained in the main tank in order to limit the production of BOG;
 - the method includes a step of routing gas from said second drum to said second compressor; this gas may be used in the installation after compression.
- 15 The invention also concerns a method of feeding with fuel gas an energy production installation, in particular on board a ship, by means of a device as described hereinabove, characterized in that it includes:
- a step A of taking up liquefied gas contained in said main tank, said liquefied gas being taken up in said first pipe at a taking up temperature,
 - 20 - a step B of expanding said taken up gas to an expansion pressure lower than a saturated vapor pressure of said taken up gas at said taking up temperature, so that some of said taken up gas is evaporated because of the effect of the expansion, and so that a remaining part of said taken up gas remains liquid and is cooled to a temperature lower than said taking up
25 temperature, in particular because said taken up gas is cooled to a saturation temperature at said expansion pressure,
 - a step C of filling said first drum and of separating, in particular by gravity, in said first drum, said liquefied gas from said cooled liquefied gas,
 - a step F of feeding the secondary tank with cooled liquefied gas from
30 said first drum and of storing said cooled liquefied gas in said secondary tank,
 - a step G of taking up natural boil-off gas in said main tank and preheating that gas,

- a step H of compressing both boil-off gas from said first drum and preheated natural boil-off gas,
- a step I of supplying said installation with said compressed gases.

The method according to the invention may include one or more of the following steps or have one or more of the following features, separately from one another or in combination with one another:

- the steps A, B, C and F are carried out continuously;
- simultaneously with the steps A, B, C and F, simultaneously with the step G, or simultaneously with the steps A, B, C, F and G, the method includes a step of taking up cooled liquefied gas from said secondary tank and injecting that gas into said main tank in order to cool the liquefied gas contained in that main tank;
- the cooled liquefied gas is injected directly into the liquefied gas and/or into the boil-off gas in said main tank.

According to a second aspect, the invention proposes a device for cooling natural boil-off gas for an energy production installation, in particular on board a ship, characterized in that it includes:

- an optional main tank for storing liquefied gas including a first natural boil-off gas outlet,
- means for taking up liquefied gas in said main tank and cooling that liquefied gas,
- a secondary tank for cooled liquefied gas configured to store liquefied gas cooled by said cooling means, and
- a first heat exchange circuit including an inlet connected to said first outlet of said main tank in order to circulate natural boil-off gas in said circuit, said first circuit being configured to cooperate with said secondary tank in order for said natural boil-off gas passing through said first circuit to be cooled by cooled liquefied gas stored in said secondary tank or coming from said secondary tank.

The main tank is optional to the extent that it may be considered as forming or not forming part of the device according to the invention. The device may for example be supplied without a main tank so that the latter does not form part of the device. Alternatively, the device once mounted on a ship for

example is combined with a main tank which therefore forms part of the device according to the invention.

The solution therefore proposes an improvement in the management of the BOG in a device adapted to the requirements for example of a ship, by cooling that BOG, and enabling:

- limitation of the capacity of the means used for cooling to that necessary for the management of the excess NBOG instead of that necessary for the management of an NBOG production peak,
- optimization of the rate of use of those means that may be used continuously, the cold source, such as the cooled liquefied gas, being storable if necessary,
- making sure that the cooling power produced is used correctly when necessary.

The solution is adapted to any type of means that cool a fluid. Here the fluid is BOG coming from the tank, cooled in the secondary tank and finally returned to the tank where it will be in a cooled state.

The device according to the invention may have one or more of the following features separately from one another or in combination with one another:

- a first separation drum an inlet of which is connected to an outlet of said first circuit to feed said first drum with cooled natural boil-off gas and with natural boil-off gas recondensed and forming cooled liquefied gas, said first drum including a first, natural boil-off gas outlet and a second, cooled liquefied gas outlet connected to said main tank in order to inject cooled liquefied gas into said main tank;
- said second tank is configured to contain a cooled liquefied gas at a pressure higher than an operating pressure of said first drum;
- the device includes at least one first compressor an inlet of which is connected to said first natural boil-off gas outlet of said main tank and/or to said first natural boil-off gas outlet of said first drum;
- said cooling means include a second heat exchange circuit that is intended to cooperate by exchange of heat with liquefied gas in said secondary

tank or coming from said secondary tank, and in which a cooling fluid circulates in order to cool said liquefied gas; so that cooled liquefied gas is generated directly in said secondary tank, and to generate cooled liquefied gas;

- said cooling means include:
 - 5 ▪ a second drum an inlet of which is connected to a first end of a first pipe a second end of which is immersed in the liquefied gas contained in said main tank, said first pipe being adapted to feed said second drum with liquefied gas, and
 - 10 ▪ a second pipe a first end of which is connected to a first cooled liquefied gas outlet of said second drum and a second end of which is connected to said secondary tank in order to feed said secondary tank with cooled liquefied gas;
- said second drum is a separation and/or expansion drum;
- the device includes a first heat exchanger a primary circuit of which has
 - 15 an inlet connected to a liquefied gas outlet of said main tank, and a secondary circuit has an inlet connected to said first pipe and an outlet connected to the inlet of said second drum;
- said second heat exchanger is not immersed in the liquefied gas in said main tank or mounted in said main tank;
- 20 - the outlet of the primary circuit of said second heat exchanger is connected to an inlet of said secondary tank in order to supply cooled liquefied gas to said secondary tank;
- the device has no components other than pumps and/or pipes immersed in the liquefied gas contained in said main tank;
- 25 - said inlet of said primary circuit is connected to an outlet of a third pump intended to be immersed in the liquefied gas in said main tank;
- the device includes:
 - 30 ▪ a first pump connected to said second end of said first pipe and intended to be immersed in said liquefied gas contained in said main tank so as to force the circulation of liquefied gas through said first pipe from said main tank to said second drum, and

- a second pump connected to said second pipe so as to force the circulation of cooled liquefied gas from said second drum to said secondary tank.
- said first pipe includes said evaporation means;
- 5 - the device includes at least one second compressor an inlet of which is connected to said first natural boil-off gas outlet of said main tank;
- said second compressor includes an outlet connected to said inlet of said first circuit;
- said inlet of said second compressor is further connected to a second gas outlet of said second drum and/or to a second gas outlet of said first drum;
- 10 - said inlet of said second compressor is connected to the outlet of said first compressor;
- said first or second compressor includes an outlet adapted to supply fuel gas, in particular to said installation;
- 15 - said inlet of said first circuit is connected to said outlet of said first or second compressor by a primary circuit of a second heat exchanger, said second heat exchanger including a secondary circuit an inlet of which is connected to said first natural boil-off gas outlet of said main tank and an outlet of which is connected to said inlet of said first or second compressor;
- 20 - said secondary tank is connected to a first end of a third cooled liquefied gas pipe a second end of which is intended to be connected to said main tank, said third pipe being adapted to route at least some of said cooled liquefied gas from said secondary tank to said main tank;
- said third pipe includes a dip tube intended to be immersed in the liquefied gas contained in said main tank and/or a spray manifold situated in said main tank in order to inject cooled liquefied gas into said main tank;
- 25 - said inlet of said first circuit is connected to said outlet of at least one compressor, such as said first or second compressor, by a primary circuit of a second heat exchanger, said second heat exchanger including a secondary circuit an inlet of which is connected to said first natural boil-off gas outlet of said main tank and an outlet of which is connected to said inlet of said first or second compressor; there may therefore be beforehand an exchange (the
- 30

exchange must be beforehand since the natural boil-off gas is not as cold as the cooled liquefied gas) between all of the natural boil-off gas (some of which goes to the installation) and a compressed part of that natural boil-off gas (the surplus over and above the consumption of the installation that is recondensed);

- 5 - the device has no components other than pumps and/or pipes immersed in the liquefied natural gas contained in said main tank.

The effects and the advantages described above in relation to the features of the device of the first aspect of the invention are naturally applicable to the same features of the device of the second aspect and vice-versa.

- 10 The present invention further concerns a ship, in particular for transporting liquefied gas, including at least one device as described hereinabove.

- The method according to the invention may include one or more of the following steps or have one or more of the following features separately from one another or combined with one another:

- 15 - the method includes:
- a step of compression of gas from said first outlet of said main tank, and/or
 - a step of compression of gas from said second outlet of said first drum,
 - 20 and/or
 - a step of compression of gas from said second outlet of said second drum;
 - the method includes a step of precooling the compressed gas before cooling thereof in said secondary tank by exchange of heat with natural boil-off
 - 25 gas taken up in said main tank and circulating in said secondary circuit of said second exchanger;
 - the method includes a step of preheating natural boil-off gas taken up in said main tank by exchange of heat with the fluid circulating in said primary circuit of said second exchanger before the compression of that gas;
 - 30 - the method includes a step of cooling the liquefied gas contained in said secondary tank;

- the method includes a step of expansion of liquefied gas so that some of said gas is evaporated by the effect of the expansion and the remainder of said gas remains liquid and is cooled;
- the method includes a step of filling said second drum and of separation,
5 in particular by gravity, in said first drum, of said gas evaporated relative to said cooled liquefied gas;
- the method includes a step of feeding said secondary tank with cooled liquefied gas;
- the method includes a step of preheating liquefied gas taken up in said
10 main tank by exchange of heat with the fluid circulating in said primary circuit of said first exchanger after expansion and before injection of said liquefied gas into said second drum;
- the method includes a step of cooling liquefied gas taken up in said main tank by exchange of heat with the fluid circulating in said secondary circuit of
15 said first exchanger before injection thereof into said secondary tank.

The effects and the advantages described above with reference to the features and steps of the method of the first aspect of the invention are naturally applicable to the same features and steps of the method of the second aspect and vice-versa.

20 The invention further concerns a method of cooling liquefied gas and/or gas from evaporation of liquefied gas for an energy production installation, in particular on board a ship, by means of a device as described above, characterized in that it includes:

- a step A of preparation of cooled liquefied gas in said secondary tank,
- 25 - a step B of taking up cooled liquefied gas in said secondary tank,
- a step C of injecting said cooled liquefied gas into said boil-off gas and/or into said liquefied gas contained in the main tank.

The invention further concerns a method of supplying fuel gas to an energy production installation, in particular on board a ship, by means of a
30 device as described hereinabove, characterized in that it includes the surveillance of at least one parameter of gas consumption by said installation, and

- if the value of said parameter is above a predetermined threshold, a step of preparation and storage of cooled liquefied gas, in particular in said secondary tank,

- if the value of said parameter is below a predetermined threshold, a step of recondensation of the natural boil-off gas produced in excess in said main tank.

The method may include a step of cooling the gas contained in said main tank using said cooled liquefied gas in order to limit the production of natural boil-off gas.

The predetermined threshold may vary, for example during a voyage of the ship. In functional terms, this threshold may correspond to the flow of NBOG to be withdrawn from the main tank in order not to have to monitor the pressure in the latter.

Advantageously, cooled liquefied gas is prepared if the production of natural boil-off gas is insufficient to satisfy the gas consumption of said installation.

Liquefied gas is preferably cooled by taking up, expanding and separating liquefied gas phases contained in said main tank.

Natural boil-off may be slowed in a number of ways: by decanting the cooled liquefied gas into the tank (for example via the manifold for spraying cooled liquefied gas into the tank, or by simple exit into the main tank), or by an exchange of cold (that is to say by an exchanger) between the natural boil-off gas and the cooled gas that enables recondensation of the natural boil-off gas (possibly also returned to the tank).

The fact that the liquefied gas is sub-cooled makes it possible not to generate boil-off gas if it is wished to slow down natural boil-off. Storage makes it possible to address high requirements for recondensation with a secondary tank of limited capacity (for example a liquefaction unit is very costly and its cost depends on its capacity).

Alternatively, the cooled gas is stored in the main tank in order to condense the natural boil-off gas in that tank, in particular if the available quantity of natural boil-off gas in that tank is greater than the demand of the

installation. The cooled gas having a higher density than the rest of the gas in the main tank, it is therefore necessary for example to cool/recondense the natural boil-off gas from the liquefied gas at the bottom of the main tank, for example below the liquid outlet or the exchanger for example. An exchanger
 5 may be provided at this location for example or a pipe provided to feed the stored cooled gas at this location to a heat exchanger (situated for example outside the tank) with the natural boil-off gas.

It is advantageous if:

- said natural boil-off gas is condensed by exchange of heat with said
 10 cooled liquefied gas, and/or
- said natural boil-off gas is compressed before said exchange of heat, and/or
- said natural boil-off gas is decompressed after said exchange of heat, and/or
- 15 - said natural boil-off gas undergoes separation of phases after said decompression.

The features and steps of the device and of the method of the first aspect of the invention may be combined with those of the device and of the method of the second aspect and vice-versa.

20

BRIEF DESCRIPTION OF THE FIGURES

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

- figure 1 is a diagrammatic view of a device according to a first embodiment of the invention which here equips a ship,
- figures 2 to 6 are diagrammatic views corresponding to figure 1 and illustrating steps of a method according to the invention,
- 30 - figure 7 is a diagrammatic view of a device according to a second embodiment of the invention which here equips a ship,

- figure 8 is a diagrammatic view of a third embodiment of a device according to the invention which here equips a ship,
- figures 9 and 10 are diagrammatic views of a device according to a fourth embodiment of the invention which here equips a ship and illustrating steps of a method according to the invention,
- figure 11 is a diagrammatic view of a device according to a fifth embodiment of the invention which here equips a ship,
- figure 12 is a diagrammatic view of a device according a sixth embodiment of to the invention which here equips a ship,
- figure 13 is a diagrammatic view of a device according to a seventh embodiment of the invention which here equips a ship.

DETAILED DESCRIPTION

Figure 1 shows a device 10 according to a first embodiment of the invention which may be considered as enabling cooling of liquefied gas and/or cooling of natural boil-off gas from liquefied gas.

The device 10 is particularly but not exclusively suitable for supplying fuel gas to a ship, such as a ship for transporting liquefied gas. The device 10 may therefore be used to supply fuel gas to an energy production installation 12, in particular on board a ship.

A ship includes a tank 14 or a plurality of tanks 14 for storing liquefied gas. The gas is for example methane or a gas mixture including methane. The or each tank 14 may contain gas in liquefied form at a predetermined pressure and a predetermined temperature, for example at atmospheric pressure and a temperature of the order of -160°C . One or more of the tanks 14 of the ship may be connected to the installation 12 by a device 10 according to the invention. Thus the number of tanks is not limiting on the invention. It is for example between 1 and 6. Each tank 14 may have a capacity between 1000 and 50 000 m^3 .

Hereinafter the expression "the tank" must be interpreted as meaning "the or each tank".

The tank 14 contains liquefied gas 14a and gas 14b resulting from boiling off, in particular natural boiling off, of the liquefied gas 14a in the tank 14. The liquefied gas 14a is naturally stored at the bottom of the tank 14 whereas the boil-off gas 14b is situated above the liquefied gas level in the tank, diagrammatically represented by the letter N.

Hereinafter "LNG" denotes liquefied gas, that is to say gas in liquid form, "BOG" denotes boil-off gas, "NBOG" denotes natural boil-off gas, and "FBOG" denotes forced boil-off gas, these abbreviations being known to the person skilled in the art because they correspond to the first letters of the associated English words.

In the embodiment represented in figure 1, pumps 16a, 16b are immersed in the LNG in the tank 14 and are preferably situated at the bottom of the tank in order to ensure that they are fed only with LNG.

Here there are two pumps 16a, 16b. The pump 16a is connected to one end, here the lower end, of a pipe 18. The pump 16b is connected to one end, here the lower end, of a pipe 20. Alternatively there may be more pumps of each type, for example to ensure redundancy of the pumps 16a and 16b or to use existing pumps such as spray pumps already present on a ship (in which case the function of the pump 16b could be provided by four spray pumps each present in one of four separate tanks.

The pipe 20 has an upper end connected to a manifold 22 for spraying droplets of LNG situated in the top part of the tank 14, above the level N. The manifold 22 is therefore configured to spray droplets of LNG into the NBOG. This makes it possible to force recondensation of the NBOG in the tank 14. The pump 16b is configured to force circulation of LNG in the pipe 20 from the bottom of the tank 14 to the manifold 22 and to ensure that LNG is sprayed in the form of droplets. In practise, a gaseous atmosphere may be present in the main tank while the NBOG may circulate in the pipes.

The pump 16a is configured to force circulation of LNG in the pipe 18 from the bottom of the tank 14 to a drum 24 connected to one end, for example the upper end, of the pipe 18. The pipe 18 includes depressurization means

such as a JT valve so as to reduce the pressure of the LNG circulating in the pipe 18 before reaching the drum 24. The means 19 are advantageously configured so that the pressure of the LNG circulating in the pipe 18 is reduced to the operating pressure of the drum 24. The means 19 include for example a
5 JT valve (as described later).

The circulation of the LNG in the pipe 18 and through the depressurization means 19 therefore leads to at least partial evaporation of the LNG before feeding the drum 24.

The drum 24 is therefore intended to be fed with partly evaporated LNG
10 coming from the tank 14. The operating pressure inside the drum 24 is less than the pressure at which the LNG is stored inside the tank 14. Feeding the drum 24 with LNG can lead to complementary evaporation of the LNG, reflected on the one hand in the generation of FBOG in the drum 24 and cooling of the LNG remaining in the drum, which is called "cooled liquefied gas". The drum 24
15 contains gas in liquefied form at a predetermined pressure and a predetermined temperature.

The drum 24 therefore contains cooled liquefied gas 24a and gas 24b resulting from evaporation, here forced evaporation, of the liquefied gas 14a coming from the tank 14. The cooled liquefied gas (LNGs) 24a is stored at the
20 bottom of the drum 24 while the boil-off gas (or FBOG) 24b is situated below the liquefied gas level in the drum 24, diagrammatically represented by the letter L.

The drum 24 has three fluid communication ports, namely an LNG inlet connected to the pipe 18, an FBOG outlet and an LNGs outlet.

The FBOG outlet is connected to an inlet of a compressor 26 an outlet
25 of which is connected to a compressor 28. The compressors 26, 28 may be two independent compressors or two compression stages of the same compressor. The compressors 26, 28 may therefore be commoned.

Here the compressor 26 is used to apply the operating pressure inside the drum 24. It is therefore configured to reduce the pressure in the drum 24
30 relative to the tank 14. The pressure difference between them may be sufficient to force the circulation of LNG from the tank to the drum 24. In this case, it is therefore clear that the pump 16a is optional. The conditions imposed on the

drum 24 by the compressor 26 are determined to generate LNGs in the expansion drum.

If the quantity of LNGs in the drum 24 is too great and there is a risk of reaching a threshold level, LNGs may be transferred from the LNGs outlet of the drum 24 to an LNGs inlet of a secondary tank 30.

Here the drum 24 and the secondary tank 30 are connected by a pipe 31 including for example a valve 33 and a pump 35. The pump 35 is configured to force the circulation of LNGs from the drum 24 to the secondary tank 30. The pump 35 is particularly useful when the tank 30 is at a higher pressure than the drum 24. The secondary tank 30 contains LNGs at a predetermined pressure and a predetermined temperature.

The secondary tank 30 is configured to store the excess LNGs produced in the drum 24. The tank 30 therefore contains cooled liquefied gas 30a and gas 30b resulting from evaporation, here natural boil-off, of the liquefied gas 14a coming from the tank 14. The cooled liquefied gas (or LNGs) 30a is stored at the bottom of the secondary tank 30 while the boil-off gas 30b is situated above the liquefied gas level in this tank, diagrammatically represented by the letter M.

The secondary tank 30 has an LNGs outlet. In the example shown, that outlet is connected by a pipe 32 on the one hand to the spray manifold 22 of the tank 14 or of each tank 14 and on the other hand to a dip tube 34 intended to dip into or to be immersed in the LNG in the tank. It is therefore clear that LNGs can feed the spray manifold 22 in order to spray droplets of LNGs into the BOG in the tank 14 and LNGs can feed the dip tube 34 in order to inject LNGs directly into the LNG in the tank 14.

The pipe 32 may be connected to the LNGs outlet of the secondary tank 30 by a valve 36. The pipe may be connected to the dip tube 34 and to the manifold 22 by a three-port valve 38.

Here the secondary tank 30 is used to cool a fluid, such as a gas or a liquid, which here is BOG from the main tank 14. Here a heat exchanger circuit 40 is associated with the secondary tank 30. Here the term association is to be understood in a broad sense, as the circuit 40 may for example be a serpentine

pipe immersed in the LNGs contained in the secondary tank 30. The circuit 40 could alternately be situated outside the tank 30. The circuit 40 is configured so that heat exchanges take place between the fluid circulating in the circuit 40 and the LNGs contained in the secondary tank 30. The fluid circulating in the circuit 5 40 is generally hotter than the LNGs, which therefore cools the fluid when it is not circulating in the circuit 40. The circuit has an inlet and an outlet.

The inlet of the circuit 40 is connected to a BOG outlet 45 of the main tank 14 which here is situated at an upper end of the tank. The BOG outlet 45 of the tank 14 is connected to an inlet of a secondary circuit 42a of a heat 10 exchanger 42 an outlet of which is connected to the inlet or to an inlet of the compressor 28.

The outlet of the compressor 28 is generally connected to the installation 12 in order to supply it with fuel gas. Some of the fuel gas leaving the compressor 28 may be taken up and rerouted via a pipe 44 that may be 15 connected to the outlet of the compressor 28 by a three-port valve 46.

The compressor 28 is configured to compress the gas (such as the NBOG from the tank) to a service pressure suited to its use in the installation 12.

The pipe 44 is connected to an inlet of the primary circuit 42b of the 20 exchanger 42 an outlet of which is connected to the inlet of the circuit 40.

The outlet of the circuit 40 is connected by a pipe 48 to a drum 50 separate from the drum 24. The pipe 48 includes a valve 52 which is preferably a Joule-Thomson effect valve in order to reduce the temperature of the gas by adiabatic expansion.

25 Joule-Thomson expansion is slow and stationary laminar expansion brought about by causing a flow of gas to pass through a plug (generally cotton wadding or raw silk) into a thermally insulated and horizontal pipe, the pressures to the left and to the right of the plug being different. For real gases Joule-Thomson expansion is generally accompanied by a temperature 30 variation: this is the Joule-Thomson effect. The exchanger 42, the circuit 40 and the valve 52 cool and partly (re)condense the BOG.

The drum 50 is intended to separate the BOG 50b that has remained in gaseous form from the (re)condensed BOG 50a before feeding the tank 14 with (re)condensed BOG. The recondensed BOG 50a is naturally stored at the bottom of the drum 50 while the boil-off gas (or BOG) 50b is situated above the liquefied gas level in the drum 50, diagrammatically represented by the letter O.

The drum 50 includes three fluid communication ports, namely a BOG inlet connected to the pipe 48, a gaseous BOG outlet and a (re)condensed BOG outlet. Here the gas BOG outlet is connected to the inlet of the compressor 28. Here the (re)condensed BOG outlet is connected to the dip tube 34, the pipe 32 and/or the spray manifold 22 in order to inject (re)condensed BOG into the tank 14.

The vacuum evaporation means formed by the pump 16a, the depressurization means 19, the drum 24 and the compressor 26 enable recovery of the latent heat of evaporation that is generally expended in a prior art evaporator to produce FBOG and the cooling power that is used in particular to cool the LNG contained in the main tank 14.

The LNGs forms a cooling power that can be stored in the secondary tank 30 when it is not needed, for example during phases in which the quantity of NBOG produced is insufficient to satisfy the demand.

The latent heat of evaporation is recovered thanks to the above device and in particular the drum 24, the operating pressure of which is less than that of the tank 14, which is for example between -20 mbarg and 250 mbarg (mbar gauge - or between -20 and 350 mbarg, or between -20 and 700 mbarg) inclusive. The operating pressure of the drum 24 is preferably between 300 and 800 mbara (mbara absolute) inclusive.

The LNG coming from the tank 14 at a saturation equilibrium corresponding to the pressure at which the LNG is stored in the tank 14 is routed to the drum 24, which is at a lower pressure than the tank 14. Consequently, this LNG is in a superheated state when it is depressurized by the means 19 and, in order to reach a saturation equilibrium, it releases its excess heat by evaporation. The LNG is then separated into LNGs and FBOG

inside the drum 24 in proportions that depend in particular on the operating pressure of the drum 24.

For example, with an operating pressure of 300 mbara the amount of evaporation of the LNG feeding the drum 24 is between 9.5 and 10% inclusive.

5 At 800 mbara that amount is between 2.3 and 3% inclusive. The remaining part is a liquid cooled to a temperature corresponding to the saturation equilibrium at the operating pressure of the drum 24. For example, with an operating pressure of 300 mbara the LNG is cooled to a temperature between -172 and -175°C (temperature reduction of -12 to -15°C), and at 800 mbara the LNG is cooled to
10 a temperature between -163 and -164°C (temperature reduction of -3 to -4°C).

The LNGs can then be evacuated thanks to the pump 35, preferably into the secondary tank 30. The pump 35 can be used to increase the pressure of the LNGs. Storing the LNGs in the secondary tank 30 makes it possible to retain the calorific power.

15 In operation, the evaporated part of the LNG feeding the drum 24 will accumulate in that drum. In order to set the pressure in the drum 24 to a predetermined value (for example between 300 and 800 mbara), the FBOG produced in the drum 24 is preferably extracted continuously. This is done by the compressor 26, which is configured to aspirate the gas contained in the
20 drum 24, with an inlet pressure corresponding to the operating pressure of the drum 24 and an outlet pressure that is for example similar to the pressure at which the LNG is stored in the tank 14. The gas processed in this way is then easy to use because it is at a pressure similar to that of the NBOG produced in the tank 14 and with the NBOG can feed the same compressor 28. That
25 compressor 28 is configured to produce fuel gas directly usable in the installation 12, for example to feed the propulsion machinery of the ship.

With the device 10 described above, to address the consumption of gas by the installation 12, the NBOG produced in the tank 14 is routed to the compressor 28 which compresses it to the pressure of use. The supplementary
30 BOG needed to satisfy the demand is produced by forced evaporation of the LNG feeding the drum 24 and then feeding the compressors 26 and 28 in succession. The pump 16a may prove necessary for feeding the drum 24 with

LNG from the tank 14, in particular if the height of the tank or the level N is between 10 and 50 m inclusive – in which case reducing the pressure in the drum 24 alone may prove insufficient to cause the LNG to circulate passively in the pipe 18.

5 The drum 24 must therefore be fed with a sufficient flow of LNG in order, in conjunction with the NBOG to meet the fuel gas consumption demand of the installation 12. For example, the supplementary flow of FBOG that would be produced in the drum 24 could be between 0 and 4000 kg/h inclusive. Consequently, as a function of the composition of the LNG and of the operating
10 pressure of the drum 24 the flow from the tank 14 to the drum 24 could be between 0 and 17.5 t/h inclusive.

 The LNGs generated in the drum 24 is stored in the secondary tank 30. The tank 30 is configured to store and to preserve the LNGs and is therefore advantageously thermally insulated. The pressure in the secondary tank 30 is
15 for example between 0.3 bara and 10 bara inclusive, to benefit from flexibility in pressure management. The temperature of the LNGs in the tank 30 is close to that of the LNGs in the drum 24, and is for example between -175 and -161°C inclusive. If necessary, for example during phases with excess NBOG, the LNGs contained in the secondary tank 30 may be routed in the pipe 32 to the
20 spray ramp 22 to spray droplets of LNGs into the BOG contained in the tank 14 and thus to cool the BOG. It may also be reinjected via the dip tube 34 into the LNG in the tank in order to cool that LNG directly.

 Excess NBOG produced relative to the demand of the installation 12 is taken off and routed to the compressor 28. It is then redirected via the valve 46
25 to the circuit 40 of the secondary tank 30 in which it is cooled by exchange of heat with the LNGs previously stored, as explained above. The excess NBOG is then directed to the valve 52 through which it will be depressurized to a pressure close to the storage pressure in the tank 14. For example, if the tank is a tank at atmospheric pressure the excess NBOG may be depressurized to a
30 pressure between 0 and 1 bar. The excess NBOG then feeds the drum 50, where it undergoes phase separation into (re)condensed BOG and gaseous BOG. The gaseous BOG is routed by the pipe 51 to the compressor 28 on the

same terms as the NBOG that would be produced in the tank 14. For its part the (re)condensed BOG is injected into the tank 14 in order to store the LNG.

Figures 2 to 6 illustrate operating phases of the device from figure 1 that may correspond to phases of operation of the ship equipped with this device.

The liquefied gas cooling method is described here in three phases:

1. A phase in which the quantity of NBOG is insufficient, also termed the FBOG phase (figures 2 and 3), for example if the ship is sailing at a speed necessitating more BOG to add to the NBOG produced in the tank or tanks 14. Additional BOG or FBOG will be supplied by the device and cooling power will be generated.

2. A phase in which excess NBOG is produced (figures 4 and 5), for example if the ship is sailing at a low speed or at anchor, the excess NBOG having to be managed in a safe and environment friendly manner.

3. A phase in which the main tank 14 of the ship is cooled (figure 6), for example before loading after the return voyage (during which BOG management is generally not necessary because the tank or tanks 14 is or are virtually empty).

1. Phase in which the quantity of NBOG is insufficient, also termed the FBOG phase (figures 2 and 3)

Figure 2 illustrates steps of the first phase in which FBOG and LNGs are produced conjointly by the device.

In order to control the pressure in the tank 14 NBOG is taken up from that tank via the outlet 45 and then feeds the compressor 28, which will produce fuel gas at a pressure acceptable for the installation 12, for example of the order of 6-7 bar, 15-17 bar or 300-315 bar. In order to top up the quantity of gas and to address the consumption requirements of the installation 12, LNG from the tank 14 is routed by the pump 16a and the pipe 18 to the depressurization means 19 in which the pressure of the LNG is reduced to the operating pressure of the drum 24. The LNG reaches the drum 24 at the operating

pressure of that drum and, because of the saturation equilibrium offset induced by the pressure difference between the drum 24 and the tank 14, some of the LNG is evaporated (this is the *flash* phenomenon) between the depressurization means 19 and the drum and the rest is cooled to the saturation temperature of the LNG at the operating pressure of the drum. A sufficient flow must be taken up from the tank 14, as explained above. The FBOG contained in the drum 24 is then evacuated and compressed by the compressor 26 to the pressure at which the LNG is stored in the tank 14. The FBOG is then compressed again by the compressor 28 to the pressure required for the installation 12. In order not to overfill the drum 24 LNGs from that drum is routed to the secondary tank 30, in particular if the level of filling of the drum with LNGs reaches a certain threshold level, for example 50%.

Figure 3 illustrates other steps of the first phase in which LNGs is stored in the secondary tank 30.

If the capacity of the secondary tank 30 is not sufficient to store the LNGs produced, LNGs contained in the tank 30 can be transferred into the bottom of the tank 14 via the pipe 32 and the dip tube 34 in order to cool the LNG in the tank 14 to below the saturation temperature of the LNG at the storage pressure in the tank 14.

2. Phase in which excess NBOG is produced (figures 4 and 5)

Figure 4 illustrates steps of the second phase in which excess BOG is recondensed.

The NBOG produced in the tank 14 is in sufficient or more than sufficient quantity to satisfy the requirements of the installation 12. In order to control the pressure in the tank 14 BOG is taken up from that tank and feeds the compressor 28 to reach the pressure required for the installation 12. The excess BOG that cannot be consumed by the installation is routed from the outlet of the compressor 28 to the exchanger 42 in which it is cooled by exchange of calories with the cold NBOG taken up directly from the tank 14 via the outlet 45. The excess BOG is then sent to the circuit 40 of the secondary tank 30 where it is again cooled by exchange of heat with the LNGs stored in

that tank, as explained above. The excess BOG is then depressurized by the valve 52 and feeds the drum 50 where the BOG (re)condensed by the exchanger 42, the circuit 40 and the valve 52 is separated from the gaseous BOG. The remaining gaseous BOG is returned to the compressor 28 to feed the
 5 installation 12.

Figure 5 illustrates steps of the second phase in which LNGs is sprayed.

Instead of recondensing the excess NBOG via the dedicated line, it is possible to transfer the LNGs contained in the secondary tank 30 to the pipe 32
 10 and then to the spray manifold 22 in order directly to recondense the BOG contained in the tank 14.

3. Phase in which the main tank of the ship is cooled (figure 6)

Figure 6 illustrates steps of the final phase.

The reliquefaction terminals where the ship loads its cargo typically
 15 necessitate a cold temperature in the tank 14 before loading in order to limit the quantity of LNG that would evaporate instantaneously (*flash evaporation*). This is generally achieved by using the manifold 22 and the associated pump 16b to spray LNG already contained in the tank 14 in order to cool the BOG in that
 20 tank. Thanks to the device 10, this operation can be effected by feeding the manifold 22 with LNGs from the secondary tank 30 and therefore LNG colder than that contained in the tank 14. In the same way, if the BOG contained in the tank 14 is not sufficient to feed the installation 12, the LNGs contained in the secondary tank 30 may be generated in the same way as during the first phase.

25

Figure 7 represents a variant embodiment of the device that differs from that from figure 1 in that it includes another heat exchanger 60. The heat exchanger 60 includes two circuits, namely a primary circuit 60a and a secondary circuit 60b.

30 The secondary circuit 60b has an inlet connected to the pipe 18, here downstream of the depressurization means 19. The secondary circuit 60b has an outlet connected to the LNG inlet of the drum 24.

The primary circuit 60a has an inlet connected by a three-port valve 62 respectively to the pump 16b and to the spray manifold 22 of the tank 14. The primary circuit 60a has an outlet connected to an LNG inlet of the secondary tank 30.

5 The secondary circuit 60b is a cold circuit, the fluid circulating in this circuit and in this instance the depressurized LNG being intended to be heated by circulation in this circuit so as to evaporate it (resulting in FBOG). The primary circuit 60a is a hot circuit, the fluid circulating in this circuit and in this instance the LNG from the tank 14 being intended to be cooled by circulation in
10 this circuit. However, the circuit 60a may not make it possible to evaporate the heavier components (ethane, propane, etc.). It is clear that depressurization upstream of the secondary circuit 60b enables reduction of the evaporation temperature, which makes it possible to generate FBOG from an exchange of heat with the LNG taken up in the tank and circulating in the primary circuit.
15 Evaporation resulting in FBOG necessitates an input of heat provided by the LNG circulating in the primary circuit, and this is therefore a cold source for cooling the LNG circulating in the primary circuit.

LNG from the tank 14 is therefore routed by the pump 16a to the depressurization means 19 and then circulates in the secondary or cold circuit
20 of the exchanger 60. In the interval, LNG from the tank is routed by the pump 16b to the primary or hot circuit of the exchanger 60. Consequently, the exchange of heat between these circuits leads to:

- heating of the depressurized and partly evaporated LNG in order to continue its evaporation, after which it is routed to the drum in order to undergo phase
25 separation,
- cooling of the LNG that feeds the secondary tank 30 to be stored therein for subsequent use.

Thereafter the device functions as initially described with reference to figures 1 to 6. Here the impacts of the exchanger 60 are:

- 30 - the pump 16a may be sized so as to cause to circulate only a predetermined maximum quantity of LNG in order to form sufficient FBOG to satisfy the

requirements of the installation 12, in addition to the NBOG. This task could be effected by the fuel pump that is generally installed in a ship,

- the capacity of the drum 24 may be reduced in that the LNG supply flow rate may be lower (the supplementary flow of FBOG alone would be used to satisfy
- 5 the fuel gas demand of the installation 12),
- because of the temperature pinch effect in the heat exchanger, the production of cooling power is lowered (loss of approximately 15% on the basis of an operating pressure of 500 mbara),
- the flow rates of LNG and LNGs circulating are lower with this solution;
- 10 consequently, the energy consumption of the pumps is reduced, which enables reduction of the energy consumption of the system.

Figure 8 shows another embodiment of a device 110 according to the invention that may be considered as enabling cooling of liquefied gas and/or

15 cooling of natural boil-off gas from liquefied gas.

The device 110 is particularly but not exclusively adapted to supply fuel gas to a ship, such as a ship for transporting liquefied gas. Thus the device may be used to feed with fuel gas an energy production installation 112 on board a ship.

20 A ship includes a tank 114 or a plurality of tanks 114 for storing liquefied gas. The gas is for example methane or a mixture of gases including methane, for example liquefied natural gas. The or each tank 114 may contain gas in liquefied form at a predetermined pressure and a predetermined temperature, for example at atmospheric pressure and at a temperature of the

25 order of -160°C. One or more tanks 114 of the ship may be connected to the installation 112 by a device 110 according to the invention. The number of tanks is therefore not limiting on the invention. It is between 1 and 6 inclusive for example. Each tank 114 may have a capacity between 1000 and 50 000 m³ inclusive.

30 Hereinafter the expression "the tank" must be interpreted as meaning "the or each tank".

The tank 114 contains liquefied gas 114a and gas 114b resulting from evaporation, in particular natural boil-off, of the liquefied gas 114a in the tank 114. The liquefied gas 114a is naturally stored at the bottom of the tank 114 whereas the boil-off gas 114b is situated above the liquefied gas level in the tank, diagrammatically represented by the letter N.

Hereinafter, "LNG" designates liquefied gas, that is to say gas in liquid form, "BOG" designates boil-off gas, "NBOG" designates natural boil-off gas, and "FBOG" designates forced boil-off gas, these abbreviations being known to the person skilled in the art because they correspond to the first letters of the associated English-language expressions.

In the embodiment represented in figure 8, the tank 114 includes a manifold 122 for spraying droplets of LNG that is situated in the top part of the tank, above the level N. The manifold 122 is therefore configured to spray droplets of LNG into the BOG. This enables forced recondensation of the BOG in the tank 14.

Here the device 110 includes cooling means 170 that are associated with a secondary tank 130 for storing LNGs.

The cooling means 170 include for example a heat exchange circuit 172 associated with the tank 130. The secondary tank 130 contains LNGs at a predetermined pressure and a predetermined temperature.

The secondary tank 130 is configured to store LNGs. The tank 130 therefore contains cooled liquefied gas 130a and gas 130b resulting from evaporation of the liquefied gas 130a. The cooled liquefied gas (LNGs) 130a is naturally stored at the bottom of the secondary tank 130 while the boil-off gas 130b is situated above the liquefied gas level, diagrammatically represented by the letter M.

The secondary tank 130 includes an LNGs outlet. In the example represented, that outlet is connected by a pipe 132 on the one hand to the spray manifold 122 of the tank 114 or each tank 114 and on the other hand to a dip tube 134 intended to be dipped into or immersed in the LNG in the tank 114. It is therefore clear that LNGs can feed the spray manifold 122 in order to spray

droplets of LNGs into the BOG in the tank 114 and LNGs can feed the dip tube 134 in order to inject LNGs directly into the LNG in the tank 114.

The pipe 132 may be connected to the LNGs outlet of the secondary tank 130 by a valve 136. The pipe may be connected to the dip tube 134 and to
 5 the manifold 122 by a three-port valve 138.

Here the secondary tank 130 is used to cool a fluid, such as a gas or a liquid, which here is BOG from the main tank 114. Here another heat exchange circuit 140 is associated with the secondary tank 130. Here the association of each circuit 140, 172 with the secondary tank 130 must be understood in a
 10 broad sense and the circuits 172 and 140 may for example be serpentine pipes immersed in the LNGs contained in the secondary tank 130. These circuits may instead be situated outside the tank 130. The circuit 140 is configured so that thermal exchanges take place between the fluid circulating in the circuit and the LNGs contained in the secondary tank 130. The fluid circulating in the circuit
 15 140 is generally hotter than the LNGs, which therefore cools the fluid as it circulates in the circuit 140. The circuit has an inlet and an outlet.

The inlet of the circuit 140 is connected to a BOG outlet 145 of the main tank 114, which here is situated at an upper end of the tank. The BOG outlet 145 of the tank 140 is connected to an inlet of a secondary circuit 142a of a
 20 heat exchanger 142 an outlet of which is connected to an inlet of a compressor 128.

The outlet of the compressor 128 is generally connected to the installation 112 in order to supply it with fuel gas. Some of the fuel gas leaving the compressor 128 may be taken up and routed by a pipe 144 that may be
 25 connected to the outlet of the compressor 128 by a three-port valve 146.

The compressor 128 is configured to compress the gas to a service pressure appropriate to its use in the installation 112.

The pipe 140 is connected to an inlet of a primary circuit 142b of the exchanger 142 an outlet of which is connected to the inlet of the circuit 140.

30 The outlet of the circuit 140 is connected by a pipe 148 to a drum 150. The pipe 148 includes a valve 152, such as a Joule-Thomson effect valve, in order to reduce the temperature of the gas through adiabatic expansion.

The exchanger 142, the circuit 140 and the valve 152 condense (in other words (re)liquefy) some of the BOG.

The drum 150 is intended to separate the (re)condensed BOG from the BOG remaining in gas form.

5 The drum 150 therefore contains BOG 150a (re)condensed (by the condensation line including for example the exchanger 142, the circuit 140 and the valve 152) and gaseous BOG 150b. The condensed BOG 150a is stored at the bottom of the drum 150 and the gaseous BOG 150b is situated above the liquefied gas level in the drum 150, diagrammatically represented by the letter
10 O.

The drum 150 has three fluid communication ports, namely a BOG inlet connected to the pipe 148, a gaseous BOG outlet and a liquid BOG outlet. Here the condensed BOG outlet is connected to the inlet of the compressor 126 by a pipe 151. Here the liquid BOG outlet is connected to the dip tube 134, the pipe
15 132 and/or the spray manifold 122 in order to store LNG in the tank 114.

Figure 9 represents a variant embodiment of the device 110 that differs from that from figure 8 by its cooling means 170.

Thus the cooling means 170 include a pump 116a immersed in the
20 LNG in the tank 114 and preferably situated at the bottom of the tank in order to ensure that it is fed only with LNG.

The pump 116a is connected to one end, here a lower end, of a pipe 118. The pipe 118 has an upper end connected to an LNGs inlet of the secondary tank 130 in order to feed LNGs into that tank. The pipe 118 passes
25 through or includes a cold generator, such as a vacuum evaporator, which may include a drum associated with a compressor, as illustrated in the previous embodiment.

The pump 116a is configured to force circulation of LNG in the pipe 118 from the bottom of the tank 114 to the secondary tank 130, in order to feed
30 LNGs to the secondary tank 130 and store it in the latter.

In the devices from figures 8 and 9 the solution is the integration of cooling means 170 into the environment of a ship in order to make best use of

that equipment to meet the requirements of the ship. The cooling means 170 are such that, in use:

- for the type represented in figure 9, LNG is routed from the tank 114 by the pump 116a to the cooling means 170 where it is cooled and then injected into the secondary tank 130 where it is stored; if the capacity of the tank 130 is not sufficient to store it, LNGs may be sent to the pipe 132 and then via the dip tube 134 inside the tank 114, which enables cooling of the LNG in the tank 114;
- for the second type represented in figure 8, the cooling means 170 cool directly the LNG stored in the secondary tank 130 through being in direct contact with the LNG, to generate LNGs.

In both cases, the result is that LNGs is stored in the secondary tank 130. The temperature of the LNGs is preferably between -180 and -160°C, inclusive, which typically corresponds to a drop in temperature of the LNG between -0.5 and -20°C. Because of the entry of heat into the secondary tank 130, some of the LNGs is able to evaporate and to be transformed into BOG 130b. If the pressure inside the secondary tank 130 reaches a predetermined threshold it can be controlled by removing some of the BOG using the compressor 126. The secondary tank 130 is designed as a function of its use, and has for example a capacity between 50 and 500 m³, for management of the BOG at sea or 1500 and 10 000 m³ for management of the BOG at anchor (2 to 5 days). The pressure in the secondary tank 130 is for example between 0.3 bara and 10 bara inclusive to have the benefit of flexibility in managing the pressure and the boil-off gas 130b.

The cooling means 170 may be used independently of the solution and its environment. The cooling means 170 preferably operate continuously whether the cooling power is needed immediately or not.

If that is necessary, LNGs may be sent to the tank 114 by means of the pipe 132 or the dip tube 134, for example to control the pressure or the temperature of the LNG contained in the tank 114.

The pressure in the tank 114 is typically controlled by taking up NBOG from the tank 114 by aspirating the NBOG by means of the compressor 126 and via the NBOG outlet 145 of the tank 114. The NBOG coming from the

compressor 126 is then used to feed the installation 112. If the load on the installation 112 is not sufficient to consume all the NBOG, then there is excess NBOG that has to be managed. In this case it is preferable to act only on the excess NBOG rather than on the LNG or all of the NBOG contained in the tank 114, as described above. Thanks to this solution, the excess NBOG coming from the compressor 126 at the operating pressure of the installation 112 (for example 6-7 bars or 15-17 bars or 300-315 bars depending on the type of installation on the ship) is sent to the heat exchanger 142 through which it will be cooled by thermal exchange with NBOG taken off via the NBOG outlet 145 in the tank 114. The excess NBOG is then sent to the thermal exchange circuit 140 of the tank 130 through which it will be cooled by exchange of heat with the LNGs contained in that tank 130. The excess NBOG is then depressurized by the JT valve 152 to the operating pressure of the drum 150 before it is fed to that drum 150. The drum 150 is regulated to a pressure close to the pressure of storage in the tank 114. Thanks to the arrangement of the BOG condensation line (which includes the heat exchanger 142, the circuit 140, the JT valve 152 and the drum 150), some of the excess NBOG is condensed. Finally, the condensed NBOG recovered in the drum 150 is reinjected into the tank 114 via the dip tube 134. (Re)condensing the NBOG in this way makes it possible to reduce the pressure of the NBOG in the tank 114.

The above device has many advantages, for example:

- The cooling means 170 are able to process all the excess NBOG and operate continuously at a medium capacity. The cooling means 170 are typically dimensioned either to manage the maximum excess NBOG and then to operate at lower capacities to manage the real variations of excess NBOG or at a balanced capacity with the excess NBOG beyond that capacity being lost. Thanks to the device 110, the cooling means 170 may be sized as a function of the mean excess NBOG capacity whilst being capable of managing all of the excess NBOG. For a standard ship, the average excess NBOG is in the range from 25 to 50% of the maximum excess NBOG. This flexibility for absorbing variations on the one hand in the production of cooling power and on the other hand the cooling power demand is procured thanks to the secondary tank 130

that is able to store LNGs colder than the LNG stored in the tank 114. In this way the cooling power is concentrated in the LNGs and ready to be used when necessary, whereas in the prior art it is diluted inside the large volume of the tank 114.

5 - The cooling power is typically employed to spray LNGs in the tank 114. The vapor phase in the tank 114 is cooled and partly condensed. In energy terms this is not ideal because some of the excess NBOG can be used to feed the installation 112. Thanks to the device 110, some of the NBOG is used to feed the installation 112 and the cooling power is used only on the excess NBOG.
10 For a typical ship the consumption of gas at anchor is in the range 15 to 30% of the NBOG.

- Thanks to the compressor 126 equipping the ship the excess NBOG is compressed to an inlet pressure of the installation 112 (typically 6-7 bars, 15-17 bars or 300-315 bars), then cooled by LNGs and phase separated before
15 returning to the main tank 114. This is more efficient than spraying LNGs into the vapor phase in the main tank 114 because it enables greater cooling of the excess NBOG and condensation of a greater proportion thereof tanks to the pressure difference.

- Some cooling means may be used under particular conditions. For example,
20 the vacuum evaporator described above may simply generate cold from supplementary FBOG needed in addition to the NBOG to feed the installation 112. Thanks to the device 110, the cooling power generated may be used when and where necessary.

25 Figures 9 and 10 illustrate operating phases of the device from figure 9, which are naturally applicable to the device from figure 8, and that may correspond to phases of the operation of the ship equipped with this device.

1. Control of tank conditions (pressure and temperature) – figure 9;
2. Management of excess NBOG – figure 10.

30

1. Control of tank conditions (pressure and temperature) – figure 9.

If the secondary tank 130 does not need to be fed with LNG from the tank 114 (for example if the energy requirements are supplied by some other energy source) and the conditions of the tank 114 must be controlled (for example wetting pressure or temperature before loading), then LNGs contained
 5 in the secondary tank 130 may be used to cool the LNG contained in the tank 114 by routing it through the pipe 132 and then the dip tube 134.

2. Management of the excess NBOG – figure 10.

As described above, the excess NBOG may be managed by causing it
 10 to circulate through the condensation line formed by the exchanger 142, the heat exchange circuit 140, the JT valve 152 and the drum 150.

Figure 11 represents an alternative.

As the installation requires feeding with gas typically at an inlet pressure
 15 greater than the storage pressure in the tank 114, the compressor 126 enables NBOG to be routed at a pressure acceptable in the installation 112. The NBOG is heated during this compression. The exchanger 142 is preferably used to recover some of the cold coming from the tank 114. This is a possibility for improved performance, but is not fundamental and therefore not indispensable.
 20 It is therefore withdrawn in the embodiment from figure 11. An outlet of the three-port valve 146 is therefore connected directly to the inlet of the circuit 140 and the NBOG outlet 145 of the tank is connected directly to the inlet of the compressor 126.

25 Figure 12 represents a variant embodiment of the device which differs from that from figure 9 in that it includes another heat exchanger 180. The heat exchanger 180 includes two circuits, namely a primary circuit 180a and a secondary circuit 180b.

The secondary circuit 180b has an input connected to a pump 182
 30 immersed in the LNGs contained in the secondary tank 130 and an outlet connected to a LNGs inlet in the tank 130 in order to reinject LNGs into the tank after the latter has exchanged calories with the fluid circulating in the primary

circuit of the exchanger 180. The primary circuit 180 is similar to the heat exchanger circuit 140 described above.

The primary circuit 180a is a hot circuit, the fluid circulating in this circuit, in this instance compressed BOG, being intended to be cooled by circulation in this circuit. The secondary circuit 180b is a cold circuit, the fluid circulating in this circuit, in this instance LNGs coming from the tank 330, being intended to be cooled by circulation in this circuit.

Figure 13 represents a variant embodiment of the device 10 which differs from that from figure 1 in that the drum 24 and the secondary tank 30 are pooled to form and to define a single tank 90 for forced boil-off of LNG coming from the tank 14 and storage of the LNGs produced in this way.

The first table below gives examples of values for various operating parameters of the device according to the invention for various ranges (wide, median and optimum).

	Wide		Median		Optimum	
Pressure (mbara)	120	950	300	800	500	600
Fraction of gas evaporated after depressurization (depressurization means 19) (%)	14.86 to 15.18	0.94 to 1.97	9.58 to 10.2	2.38 to 3.37	6.06 to 6.87	4.68 to 5.57
Cooled gas flow rate supplied by the pump 35 (t/h)	15.35 to 31.08	138 to 371.6	24.23 to 51.42	79.32 to 197.7	37.37 to 84.69	46.81 to 109.9
Flow rate of gas supplied by the pump 16a (t/h)	18.09 to 34.95	140.8 to 374.7	26.99 to 55.48	82.11 to 202.6	40.14 to 89	49.58 to 114.4

Size of secondary tank 30 if connected directly to the manifold 22 (m ³)	1907 to 2120	20021 to 86037	2964 to 3483	10476 to 16799	4595 to 5810	5810 to 7611
Size of secondary tank 130 in order to recondense BOG (m ³)	1312 to 1778	3506 to 32049	1714 to 2915	2989 to 12136	2160 to 5164	2405 to 7224
Temperature of BOG cooled by circuit 40 (°C)	-178.2 to -180.4	-160.6 to -159	-172.6 to -170.5	-162.5 to -161	-167.6 to -165.7	-165.7 to -164
Fraction of BOG recondensed after expansion by valve 52 (%)	93.16 to 100	81.63 to 98.86	87.94 to 100	82.49 to 100	85 to 100	84 to 100

The second table indicates the same types of parameters but targeted on more common liquefied gas compositions and in particular liquefied natural gas, such as methane or a mixture of gases containing methane.

5

	Wide		Median		Optimum	
Pressure (mbara)	120	950	300	800	500	600
Fraction of gas evaporated after depressurization (depressurization means 19) (%)	14.86 to 15.18	0.94 to 1.97	9.58 to 10.2	2.38 to 3.37	6.06 to 6.87	4.68 to 5.57
Cooled gas flow rate supplied by the pump 35 (t/h)	15.35 to 19.88	138 to 261.1	24.23 to 32.59	19.32 to 142.9	37.37 to 53.56	46.81 to 70.44

Flow rate of gas supplied by the pump 16a (t/h)	18.09 to 22.86	140.8 to 264	26.99 to 35.59	82.11 to 2146	40.14 to 56.59	49.58 to 73.48
Size of secondary tank 30 if connected directly to the manifold 22 (m ³)	1907 to 2028	20021 to 42375	2964 to 3317	10476 to 14470	4595 to 5504	5810 to 6750
Size of secondary tank 130 in order to recondense BOG (m ³)	1312 to 1523	3506 to 5944	1714 to 2090	2989 to 4482	2160 to 2811	2405 to 3268
Temperature of BOG cooled by circuit 40 (°C)	-179.1 to -180	-160.6 to -159.5	-172.6 to -171.1	-162.5 to -161.4	-167.6 to -166.1	-165.7 to -164.7
Fraction of BOG recondensed after expansion by valve 52 (%)	100	92.47 to 98.86	98.69 to 100	93.59 to 100	96.26 to 100	95.24 to 100

The hydrostatic pressure at the lower end of the pipe 18 (the pump generally being at a stable depth) varies as a function of the level of filling of the main tank

- 5 The temperature of the liquefied gas in the drum 24 is equal to the "temperature of the BOG cooled by the circuit 40 (°C)" less 2°C for example, which corresponds to the "pinch effect" of the exchanger.

The fraction of gas evaporated after depressurization is given by the formula:

10 $X = (H_{l,u} - H_{l,d}) / (H_{v,d} - H_{l,d})$

in which:

X is the mass percentage of evaporated liquid,

$H_{l,d}$ (J/Kg) is the enthalpy of the upstream liquid at the upstream temperature and pressure,

$H_{v,d}$ (J/Kg) is the enthalpy of the evaporated gas at the downstream pressure and corresponding to the saturation temperature, and

- 5 $H_{l,d}$ (J/Kg) is the enthalpy of the residual liquid at the downstream pressure and corresponding to the saturation temperature.

CLAIMS

1. A device (10, 110) for cooling natural boil-off gas for an energy production installation (12, 112), on board a ship, characterized in that it includes:

- 5 - a main tank (14, 114) for storing liquefied gas including a first natural boil-off gas outlet (45, 145),
- means (170) for taking up liquefied gas in said main tank and cooling that liquefied gas,
- a secondary tank (30, 130) for cooled liquefied gas configured to store liquefied
- 10 gas cooled by said cooling means,
- a first heat exchange circuit (40, 140) including an inlet connected to said first outlet of said main tank in order to circulate natural boil-off gas in said circuit, said first circuit being configured to cooperate with said secondary tank in order for said natural boil-off gas passing through said first circuit to be cooled by cooled
- 15 liquefied gas stored in said secondary tank or coming from said secondary tank, and
- a first separation drum (50, 150) an inlet of which is connected to an outlet of said first circuit (40, 140) to feed said first drum with cooled natural boil-off gas and with natural boil-off gas recondensed and forming cooled liquefied gas, said
- 20 first drum including a first, natural boil-off gas outlet and a second, cooled liquefied gas outlet connected to said main tank in order to inject cooled liquefied gas into said main tank,
- wherein said cooling means include:
 - a second drum (24) an inlet of which is connected to a first end of a first pipe
 - 25 (18, 118) a second end of which is intended to be immersed in the liquefied gas contained in said main tank (14, 114), said first pipe being adapted to feed said second drum with liquefied gas, and
 - a second pipe (31) a first end of which is connected to a first cooled liquefied gas outlet of said second drum and a second end of which is connected to said
 - 30 secondary tank in order to feed said secondary tank (30, 130) with cooled liquefied gas,
 - wherein said first pipe (18, 118) includes evaporation means (19).

2. The device (10, 110) as claimed in claim 1, including at least one first compressor (26, 126) an inlet of which is connected to said first natural boil-off gas outlet of said main tank (14, 114) and/or to said first natural boil-off gas outlet of said first drum (50, 150).

5 3. The device (10, 100) as claimed in claim 1 or 2, including a first heat exchanger (60) a primary circuit (60a) of which has an inlet connected to a liquefied gas outlet of said main tank (14) and an outlet connected to an inlet of said secondary tank (30) in order to feed said secondary tank with liquefied gas, and a secondary circuit (60b) has an inlet connected to said first pipe (18) and an
10 outlet connected to the inlet of said second drum (24).

4. The device (10, 110) as claimed in any one of the preceding claims, including:

- a first pump (16a, 116a) connected to said second end of said first pipe (18, 118) and intended to be immersed in said liquefied gas contained in said main
15 tank (14, 114) so as to force the circulation of liquefied gas through said first pipe from said main tank to said second drum (24), and
- a second pump (35) connected to said second pipe (31) so as to force the circulation of cooled liquefied gas from said second drum (24) to said secondary tank (30, 130).

20 5. The device (10, 110) as claimed in any one of the preceding claims, including at least one second compressor (28, 128) an inlet of which is connected to said first natural boil-off gas outlet (45, 145) of said main tank (14, 114), said second compressor including an outlet connected to said inlet of said first circuit (40, 140).

25 6. The device (10, 110) as claimed in claim 5, in which said inlet of said second compressor (28, 128) is further connected to a second gas outlet of said second drum (24) and/or to a second gas outlet of said first drum (50, 150).

7. The device (10, 110) as claimed in claim 5 or 6 when dependent on claim 2, in which said inlet of said second compressor (28) is connected to the outlet of
30 said first compressor (26).

8. The device (10, 110) as claimed in any one of claims 5 to 7 when dependent on claim 2, in which said first or second compressor (26, 28, 126) includes an outlet adapted to supply fuel gas, to said installation (12, 112).

9. The device (10, 110) as claimed in any one of claims 5 to 8 when dependent on claim 2, in which said inlet of said first circuit (40, 140) is connected to said outlet of said first or second compressor (26, 28, 126) by a primary circuit (42b, 142b) of a second heat exchanger (42, 142), said second heat exchanger including a secondary circuit (42a, 142a) an inlet of which is connected to said first natural boil-off gas outlet (45, 145) of said main tank (14, 114) and an outlet of which is connected to said inlet of said first or second compressor.

10. The device (10, 110) as claimed in any one of the preceding claims, in which said secondary tank (30, 130) is connected to a first end of a third cooled liquefied gas pipe (32, 132) a second end of which is connected to said main tank (14, 114), said third pipe being adapted to route at least some of said cooled liquefied gas from said secondary tank to said main tank.

11. The device (10, 110) as claimed in the preceding claim, in which said third pipe includes a dip tube (34, 134) intended to be immersed in the liquefied gas contained in said main tank (14, 114) and/or a spray manifold (22, 122) situated in said main tank in order to inject cooled liquefied gas into said main tank.

12. A ship for transporting liquefied gas, including at least one device (10, 110) as claimed in any one of the preceding claims.

13. A method for feeding fuel gas to an energy production installation (12, 112), on board a ship, by means of a device (10, 110) as claimed in any one of claims 1 to 11, characterized in that it includes the surveillance of at least one parameter of consumption of gas by said installation, and

- if the value of said parameter is above a predetermined threshold, a step of preparing and storing cooled liquefied gas, in said secondary tank,
- if the value of said parameter is below a predetermined threshold, a step of recondensing natural boil-off gas produced in excess in said main tank.

14. The method as claimed in the preceding claim, in which cooled liquefied gas is prepared if the production of natural boil-off gas is insufficient to satisfy the gas consumption of said installation.

15. The method as claimed in the preceding claim, in which liquefied gas is cooled by taking up, expanding and separating liquefied gas phases contained in said main tank.

16. The method as claimed in any one of claims 13 to 15, in which said cooled
5 liquefied gas is stored in the main tank in order to condense natural boil-off gas in that tank, if the available quantity of natural boil-off gas in that tank is greater than the requirement of said installation.