

BOG Recondenser and LNG Storage System Provided with Same

The present invention relates to a BOG recondenser for recondensing BOG of LNG and an LNG storage system provided with the same.

5 When a low temperature liquid such as liquefied natural gas (LNG) or liquefied petroleum gas (LPG) is stored, a recondenser is commonly used to liquefy and condense boil-off gas (BOG) vaporised, for example, by natural external heat input.

A method is known for compressing BOG generated from a storage tank for storing LNG by a compressor and recondensing BOG by heat exchange with LNG supplied in a subcooled
10 state from the LNG storage tank (for example, Patent Literature 1). According to this method, the recondensed LNG is returned to the LNG storage tank.

A method has been proposed for using liquid nitrogen instead of LNG as the coolant of the heat exchanger in the recondenser used when storing LNG (for example, Patent Literature 2).

15 It is common knowledge that LNG stored in a storage tank contains nitrogen. This is because, besides nitrogen contained in nitrogen gas generated from a gas field, nitrogen used for purging natural gas storage equipment and nitrogen for instrumentation are found in LNG. The nitrogen mixed with LNG reduces the liquid density of LNG. As a result, LNG having different liquid densities are present in the same LNG storage tank and form liquid layers
20 having different liquid densities in the LNG storage tank, and this is a cause of the rapid vaporisation of LNG in a LNG storage tank known as rollover. When pressure in a storage tank increases rapidly due to vaporisation, there is a risk of damage to the storage tank. Therefore, techniques have been developed for removing nitrogen in LNG (for example, Patent Literature 3).

25 PRIOR ART LITERATURE

PATENT LITERATURE

PATENT LITERATURE 1 Japanese Unexamined Utility Model Patent Publication No. H5-6299

PATENT LITERATURE 2 Japanese Unexamined Patent Publication No. 2002-295799

30 PATENT LITERATURE 3 International Patent Publication No. 2011/064605

SUMMARY OF THE INVENTION

PROBLEMS THAT THE INVENTION IS TO SOLVE

A recondenser that uses a compressor (for example, Patent Literature 1) has the problems that the compressor is expensive and has a complex structure with rotating parts, which complicates maintenance.

5 Systems for recondensing compressed BOG by heat exchange with LNG supplied in a subcooled state from an LNG storage tank have been designed on the premise that LNG is consumed continuously (for example, Patent Literature 1). If LNG is not continuously consumed or LNG consumption fluctuates greatly, however, the BOG is not suited to recondensing because fluctuation in heat exchange is too great.

10 In the case that liquid nitrogen is used as the coolant in a BOG recondenser, the latent heat of the liquid nitrogen is usually used (for example, Patent Literature 2). Using only latent heat, however, increases the temperature difference between liquid nitrogen and BOG, and has poor heat efficiency. Furthermore, the sensible heat of the low temperature nitrogen gas vaporised by heat exchange with BOG is not used, which also has poor heat efficiency. Therefore, this method has the problem of increasing consumption of the liquid nitrogen used
15 in heat exchange.

Using both the latent heat of the liquid nitrogen in a single heat exchanger and the sensible heat of nitrogen gas after vaporising means that the coolant is handled in different states, and applying these to a system having a large load fluctuation such as BOG recondensation may make it difficult to control the temperature of the coolant and ultimately
20 lead to a sudden pressure rise or pressure drop on the BOG side. Although how to respond to such a pressure rise or pressure drop may influence the design of the LNG buffer tank and heat exchangers, such design is not easy in terms of choice of materials and complexity of structure.

Because all of these methods for recondensing the entire amount of BOG also recondense
25 the nitrogen contained in the BOG, the LNG in the storage tank continues to contain nitrogen. Therefore, there is a risk that the rapid vaporisation of LNG known as rollover will occur in the LNG storage tank.

A method for removing nitrogen in LNG by rectification or the like was proposed by Patent Literature 3, but has the problem that large-scale rectification equipment must be
30 installed and operating the rectification equipment requires much power. Specifically, to rectify raw material LNG after temporarily decompressing by an expansion turbine, the gas or liquid recovered from the bottom of the tower must be boosted again, and this process requires power. In the case that nitrogen is condensed in the head of the tower before

removing, more power is required to compress and recondense the gas in the head to return to the rectification tower as a stationary reflux liquid.

In view of this situation, an objective of the present invention is to provide a BOG recondenser for recondensing BOG of LNG with high heat exchange efficiency while removing nitrogen in the BOG of LNG and without using a compressor, and an LNG storage system using the same.

MEANS OF SOLVING THE PROBLEMS

Invention 1

- 10 The BOG recondenser according to an aspect of the present invention is
- a BOG recondenser for recondensing boil-off gas (BOG) vaporised from LNG in an LNG buffer tank, characterized in that:
 - a BOG draw-off pipe for drawing BOG from the LNG buffer tank,
 - a first condenser for condensing at least some of the BOG delivered by the BOG
 - 15 draw-off pipe,
 - a first gas supply section for supplying at least some of the gas in the first condenser from the first condenser to a second condenser,
 - a first return pipe for returning at least some of the recondensed BOG in the first condenser from the first condenser to the LNG buffer tank,
 - 20 - a second return pipe for returning the recondensed BOG in the second condenser from the second condenser to the LNG buffer tank, and
 - a second exhaust pipe for expelling at least some of the gas in the second condenser from the second condenser, are provided;
 - the first condenser has a first heat exchanger;
 - 25 - the second condenser has a second heat exchanger; and
 - at least some of the coolant exchanging heat with the BOG in the second condenser in the second heat exchanger is made to also exchange heat with the BOG in the first condenser in the first heat exchanger.

The BOG recondenser according to the present invention does not require the expensive rotating machine of a compressor and requires no troublesome compressor maintenance. The BOG recondenser according to the present invention can use the cold of the coolant effectively and obtain high heat exchange efficiency because the coolant used in the second heat exchanger is also used in the first heat exchanger.

According to the present invention, in the first heat exchanger, the relatively high-
temperatur BOG generated from the LNG buffer tank is cooled by heat exchange with coolant
in a state in which the temperature of the coolant itself has been raised by heat exchange in
the second heat exchanger. In the second heat exchanger, the BOG cooled in the first heat
5 exchanger is cooled more by coolant in a state in which the temperature is lower than the
coolant in the first heat exchanger. Therefore, the temperature difference between the heat-
exchanged fluids in either the first heat exchanger or the second heat exchanger is relatively
small compared with when BOG generated from an LNG buffer tank exchanges heat with
coolant in a liquid state in a single heat exchanger.

10 The BOG recondenser according to the present invention can also expel at least some of
the nitrogen-rich gas in the second condenser by the second exhaust pipe, and thereby remove
nitrogen from the BOG.

The first condenser and the second condenser in the present invention may be installed in
parallel in an upper portion of the LNG buffer tank. In this case, the first gas supply section
15 may be, for example, a gas supply pipe for introducing gas drawn from the first condenser to
the second condenser.

The first condenser and the second condenser in the present invention may be installed in
series in an upper portion of the LNG buffer tank. In this case, the first gas supply section is
located in an intermediate area between the first condenser and the second condenser.

20 The LNG buffer tank in the present invention is not specifically limited provided that it is
a storage tank for supplying and storing LNG, and may be the primary storage tank for storing
LNG or a buffer tank for temporarily storing LNG until the BOG condensed in the first
condenser and/or the second condenser is returned.

The coolant used in the present invention is not specifically limited provided that it is a
25 coolant at a temperature at or below the condensation point of BOG, and may be, for
example, liquid nitrogen or liquid air.

Invention 2

In the BOG recondenser according to an aspect of the present invention, the second heat
exchanger is a latent heat exchanger for exchanging heat between the latent heat of the
30 coolant and the heat quantity of the BOG in the second condenser, and the first heat
exchanger is a sensible heat exchanger for exchanging heat between the sensible heat of the
coolant and the heat quantity of the BOG in the first condenser.

According to the present invention, coolant in a liquid state is first introduced to the
second heat exchanger for heat exchange. The temperature is raised by heat exchange, which

vaporises the coolant to become a gaseous state. The coolant in a gaseous state is introduced to the first heat exchanger for heat exchange. Because the cold of the latent heat portion of the coolant is used for heat exchange in the second heat exchanger and the sensible heat of the coolant is used for heat exchange in the first heat exchanger, the heat quantity of the coolant
5 can be used effectively for effective heat exchange. Therefore, the consumption amount of coolant used for cooling BOG can be reduced.

According to the present invention, in the first heat exchanger, the relatively high-temperature BOG generated from the LNG buffer tank is cooled by heat exchange with coolant in a gaseous state at a higher temperature than the coolant in a liquid state. In the
10 second heat exchanger, the BOG cooled by heat exchange with the coolant in a gaseous state is cooled more by coolant in a liquid state at a lower temperature than the coolant in a gaseous state. Therefore, a single-phase coolant is used in both the first heat exchanger and the second heat exchanger. As a result, the structural design of the heat exchangers is simplified.

The present invention, which uses latent heat and sensible heat separately, is especially
15 advantageous in the case that the temperature of BOG fluctuates greatly.

BOG is known to contain nitrogen because nitrogen gas becomes mixed with LNG during mining or is used to purge LNG equipment. The content of nitrogen in BOG fluctuates greatly due to factors such as the structure of the equipment to be purged and the length of time that LNG is stored in the equipment. The condensation point of BOG also fluctuates
20 associated with fluctuation in the content of nitrogen in BOG.

The temperature of BOG changes due to the features of the LNG equipment and the temperature of the transfer line for transferring LNG to the LNG buffer tank. In the case that LNG is transferred from an LNG ship or the like to an LNG buffer tank (including receiving, bunkering, or shipping LNG from an LNG ship to an LNG buffer tank), the temperature of
25 BOG tends to change to a higher temperature.

In such a case, the present invention, in which BOG precooled in the first heat exchanger is cooled more and condensed in the second heat exchanger, is especially advantageous. In the case that the condensation point of BOG has changed to a higher temperature or the temperature of BOG has become a high temperature, precooling by coolant in a gaseous state
30 in the first heat exchanger ameliorates the heat load and minimises the consumption amount of liquid coolant in the second heat exchanger. The purpose of this is to improve the heat efficiency of the entire heat exchanger system including the first heat exchanger and the second heat exchanger.

According to the conventional method using a single heat exchanger, in the case of heat exchange using -170°C liquid nitrogen, for example, the required amount of liquid nitrogen increases about 5% when BOG at a temperature of -150°C is compared with BOG at a temperature of -162°C when introduced in the heat exchanger. In this case, the heat exchanger generates -170°C gaseous nitrogen.

According to the present invention in which gaseous nitrogen is used for precooling in the first heat exchanger, by contrast, the heat quantity required to recondense BOG in the second heat exchanger is reduced because -150°C BOG can be cooled to about -162°C in the first heat exchanger and the temperature of BOG when introduced to the second heat exchanger can be lowered. As a result, the consumption amount of liquid nitrogen can be minimised.

Invention 3

In the BOG recondenser according to an aspect of the present invention, an opposite end of the BOG draw-off pipe from the first condenser may be disposed lower than the first heat exchanger;

- an opposite end of the first return pipe from the first condenser may be disposed lower than the opposite end of the BOG draw-off pipe from the first condenser;
- the opposite end of the first gas supply section from the first condenser may be disposed higher than the first heat exchanger;
- the opposite end of the first gas supply section from the second condenser may be disposed lower than the second heat exchanger; and
- the opposite end of the second return pipe from the second condenser may be disposed lower than the opposite end of the first gas supply section from the second condenser.

According to the present invention, BOG is supplied from the lower portions of the first condenser and the second condenser, and recondensed BOG is expelled outside the condensers from the bottom portions. Meanwhile, the uncondensed component is expelled outside the condensers from the upper portions of the condensers. This produces a rectification effect by contact between BOG and recondensed BOG in the first condenser and the second condenser. This rectification effect causes components having a lower condensation point than BOG, such as nitrogen, to concentrate in the upper portion of the condenser, and can reduce the content of low condensation point components (for example, nitrogen) in recondensed BOG.

Invention 4

In the BOG recondenser according to an aspect of the present invention, the second condenser may be provided with a second exhaust pipe for drawing gas in the second condenser, and an exhaust pressure control valve for exercising control such that the pressure in the second exhaust pipe is a predetermined value or lower; and

5 the second exhaust pipe may be disposed higher than the second heat exchanger.

The second exhaust pipe is a pipe for removing waste nitrogen gas from the gas phase portion of the second condenser.

The gas phase portion in the second condenser comprises BOG containing much nitrogen gas. The concentration of this nitrogen gas is determined by the temperature and pressure in
10 the second condenser. Therefore, nitrogen gas having a predetermined concentration can be expelled from the second exhaust pipe by using an exhaust pressure control valve to keep the pressure in the second condenser at or below a predetermined value (for example, a value lower than a range from 1.013 bar to 1.5 bar). As a result, nitrogen contained in BOG can be removed and recondensed BOG from which nitrogen has been removed can be returned to the
15 LNG buffer tank, which improves the quality of the heat quantity of LNG in the LNG buffer tank.

Invention 5

In the BOG recondenser according to an aspect of the present invention, the second heat exchanger may be provided with a second coolant delivery channel for drawing the coolant
20 from the second heat exchanger, a coolant buffer tank for collecting coolant delivered via the second coolant delivery channel, a second coolant return channel for returning at least some of the liquid phase of the coolant in the coolant buffer tank to the second heat exchanger, and a second coolant flow rate control valve for controlling the circulation amount of the coolant.

Invention 6

25 In the BOG recondenser according to an aspect of the present invention, the coolant buffer tank may also be provided with a first coolant return channel for drawing at least some of the gas phase of the coolant in the coolant buffer tank to the first heat exchanger.

Invention 7

30 In the BOG recondenser according to an aspect of the present invention, the coolant may be liquid nitrogen and/or liquid air.

The coolant in the second heat exchanger is recirculated to the second heat exchanger via the second coolant delivery channel, the coolant buffer tank, and the second coolant return channel. This is so that the coolant can be circulated using fluctuation in coolant density caused by the difference in coolant temperature produced by heat exchange between the BOG

and the coolant (thermosyphon). In the coolant buffer tank, the heat exchange function using latent heat and the heat exchange function using sensible heat can be separated by sending the gas phase portion of the coolant to the first heat exchanger and the liquid phase portion of the coolant to the second heat exchanger.

5 After the coolant has been separated into a gas and a liquid in the coolant buffer tank, the coolant in the heat exchangers is a single phase rather than a gas-liquid mixed phase (the coolant used in the first heat exchanger is only gas phase and the coolant used in the second heat exchanger is only liquid phase). This can facilitate temperature control in the first heat exchanger and the second heat exchanger.

10 Specifically, the temperature of the first heat exchanger may be controlled by adjusting the flow rate of the coolant in the first coolant return channel for introducing gas-phase coolant from the coolant buffer tank to the first heat exchanger.

 The temperature of the second heat exchanger is realised by controlling the liquid level of coolant in the second heat exchanger to control the heating surface area between the coolant and the BOG. If the temperature in the second heat exchanger has dropped below a desired
15 temperature, the second coolant flow rate control valve is closed or the opening is reduced to collect gas-phase coolant in front of the second coolant flow rate control valve. This raises the temperature of the second heat exchanger by decreasing the amount of gas-phase coolant flowing into the second heat exchanger from the coolant buffer tank via the second coolant
20 return channel. Conversely, if the temperature of the second heat exchanger must be lowered, the second coolant flow rate control valve is closed to reduce the pressure of the gas-phase coolant in front of the second coolant flow rate control valve. This increases the amount of gas-phase coolant flowing to the second heat exchanger from the second coolant return channel and lowers the temperature of the second heat exchanger.

25 Using a single-phase coolant instead of a gas-liquid mixed phase can be said to facilitate temperature control in both heat exchangers.

 Although the coolant supplied to the second heat exchanger may be supplied at a temperature lower than the freezing point of BOG, such as liquid nitrogen in a subcooled state (for example, -196°C), the buffering effect of disposing a coolant buffer tank can prevent the
30 operating temperature of the heat exchanger reaching the freezing point of BOG. This means that coolant can be used in a state having more cold quantity, and can reduce the consumption amount of coolant compared with using a coolant controlled in temperature so as to avoid condensing BOG.

The coolant may be a coolant capable of cooling and condensing BOG at or below the condensation point of BOG, and may be, for example, liquid nitrogen or liquid air. The coolant may also be a mixture of liquid nitrogen and liquid air. The coolant may be in a liquid state or a gaseous state.

5 Being inert and inflammable, liquid nitrogen is especially advantageous in terms of safety and in terms of use in equipment handling flammable LNG. Where liquid nitrogen requires separating nitrogen from air, liquid air does not require a separation operation, and thus is useful in terms of energy. Therefore, liquid air may be used instead of liquid nitrogen as a coolant for recondensing BOG, or nitrogen may be used as an intermediary medium for
10 exchanging heat with liquid air, and liquefied liquid nitrogen may be used to exchange heat with BOG.

Invention 8

The LNG storage system according to an aspect the present invention is provided with the BOG recondenser according to any one of Inventions 1 to 7, an LNG tank for storing
15 LNG, an LNG tank BOG exhaust pipe for introducing BOG in the LNG tank to the LNG buffer tank, and an LNG buffer tank LNG exhaust pipe for delivering at least some of the liquid phase of the LNG in the LNG buffer tank into the LNG tank.

A condenser is attached for directly recondensing LNG in the LNG tank where LNG was received from an LNG ship or the like, and is capable of returning recondensed BOG directly
20 to the LNG tank. Alternately, recondensed BOG may be temporarily received in the LNG buffer tank, and subsequently returned from the LNG buffer tank to the LNG tank using a pump or other means. The LNG buffer tank has a function for assuring a net positive suction head (NPSH). When recondensed BOG is returned from the LNG buffer tank to the LNG tank, the LNG buffer tank has a function for receiving the gas phase portion in the LNG tank
25 to lessen boosting the pressure in the LNG tank.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing a configuration example of the BOG recondenser of Embodiment 1;

30 FIG. 2 is a diagram showing a configuration example of the LNG storage system of Embodiment 2; and

FIG. 3 is a diagram showing a configuration example of the BOG recondenser of Embodiment 1;

DESCRIPTION OF THE EMBODIMENTS

Several embodiments of the present invention will be described hereinafter. The embodiments described hereinafter describe an example of the present invention. The present invention is not in any way limited to the following embodiments, and includes various modifications executed within a range that does not alter the essence of the present invention.

5 The configurations described hereinafter do not necessarily comprise all of the essential configurations of the present invention.

Embodiment 1

The BOG recondenser of Embodiment 1 will be described with reference to FIG. 1.

A BOG recondenser 1 has an LNG buffer tank 12, a first condenser 111, and a second
10 condenser 211. The first condenser 111 has a first heat exchanger 112. The second condenser 211 has a second heat exchanger 212.

The LNG buffer tank 12 may be any tank having a structure capable of storing LNG and may receive LNG directly from an LNG ship or the like, but may also be a buffer tank for temporarily holding recondensed BOG recondensed from the BOG generated from the LNG
15 tank (not shown) in which LNG was received from the LNG ship.

The BOG generated in the LNG buffer tank 12 is introduced by a BOG draw-off pipe 11 to the first condenser 111. At least some of the BOG introduced to the first condenser 111 is recondensed by heat exchange with coolant in the first heat exchanger 112. The recondensed BOG is returned to the LNG buffer tank 12 via a first return pipe 113. Of the BOG introduced
20 to the first condenser 111, the portion not recondensed in the first condenser 111 is introduced by a first gas supply section 114 to the second condenser 211. At least some of the BOG introduced to the second condenser 211 is recondensed by heat exchange with coolant in the second heat exchanger 212. The recondensed BOG is returned to the LNG buffer tank 12 via a second return pipe 213.

25 The first gas supply section 114 is a pipe for circulating BOG.

The LNG buffer tank 12 in the present invention is not specifically limited provided that it is a storage tank for supplying and storing LNG, and may be the primary storage tank for storing LNG or a buffer tank for temporarily storing LNG until the BOG condensed in the first condenser 111 and the second condenser 211 is returned to the primary storage tank for
30 storing LNG.

The coolant used in the second heat exchanger 212 is introduced to the second heat exchanger 212, and following heat exchange with the BOG in the second condenser 211, is introduced to the first heat exchanger 112 via a second coolant delivery channel 216. The

coolant introduced to the first heat exchanger 112 exchanges more heat with the BOG in the first condenser 111.

The coolant in the present embodiment may be a coolant capable of cooling and condensing BOG at or below the condensation point of BOG, and may be, for example, liquid nitrogen or liquid air. The coolant (for example, nitrogen) is introduced to the second heat exchanger 212 in a liquid state. The temperature of the coolant (liquid nitrogen) at this time may be any temperature at or below the liquefaction temperature of BOG; for example, -170°C. Following heat exchange with the BOG in the second heat exchanger 212, the liquid nitrogen is introduced by the first coolant return channel 115 to the first heat exchanger 112. Although the coolant may be introduced to the first heat exchanger 112 in a liquid state, some or all of the coolant may be introduced to the first heat exchanger 112 in a vaporised state. In the first heat exchanger 112, heat exchange is performed at a higher temperature than the second heat exchanger 212 (for example, -162°C), and some of the BOG in the first condenser 111 is condensed. Following heat exchange in the first heat exchanger 111, some or all of the coolant is in a vaporised state. Although this coolant may be discarded, the coolant may be cooled again to liquefy and reuse.

Positional relationship between condensers and pipes

The opposite end of the BOG draw-off pipe 11 from the first condenser 111 is disposed lower than the lower end of the first heat exchanger 112. This is so that exchanging heat while causing BOG to circulate upward from the lower end of the first heat exchanger 112 brings the BOG circulating upward from below into contact with recondensed BOG circulating downward from above to obtain a rectification effect. The gas containing many low boiling point compounds (for example, nitrogen) as a result of rectification collects in the upper portion of the first condenser 111, and this gas is delivered from the upper portion of the first condenser 111 to the second condenser 211 via the first gas supply section 114.

For the same reason, the opposite end of the first gas supply section 114 from the second condenser 211 is disposed lower than the lower end of the second heat exchanger 212. In the second condenser 211, BOG circulates upward from below the second heat exchanger 212, and comes into contact with recondensed BOG circulating downward from above. The gas containing even more low boiling point compounds (for example, nitrogen) as a result of rectification collects in the upper portion of the second condenser 211, and is expelled by the second exhaust pipe 214 as waste nitrogen.

The recondensed BOG collected in the lower portion of the first condenser 111 is returned by the first return pipe 113 to the LNG buffer tank 12. The recondensed BOG

collected in the lower portion of the second condenser 211 is returned by the second return pipe 213 to the LNG buffer tank 12. Because a certain amount of recondensed BOG collects in the bottom of the first condenser 111 and the second condenser 211, the opposite end of the BOG draw-off pipe 11 from the first condenser 111 is preferably positioned above the liquid level of the collected recondensed BOG.

Coolant buffer tank

Coolant may be introduced directly from the second heat exchanger 212 to the first heat exchanger 112, or may be introduced by way of a coolant buffer tank 13. The coolant drawn from the second heat exchanger 212 is introduced by the second coolant delivery channel 216 to the coolant buffer tank 13. Of the coolant introduced to the coolant buffer tank 13, the liquid phase portion collects in the lower portion of the coolant buffer tank 13, and is delivered again to the second heat exchanger 212 by a second coolant return channel 215. Of the coolant introduced to the coolant buffer tank 13, the gas phase portion collects in the upper portion of the coolant buffer tank 13, and is delivered to the first heat exchanger 112 by the first coolant return channel 115.

The coolant may be cooled in the coolant buffer tank 13 to partially liquefy. Liquid air or liquid nitrogen, for example, may be used to cool the coolant. Although liquid nitrogen may be used as the coolant and liquid nitrogen may be used to cool the liquid nitrogen, liquid air may also be used.

The coolant is temporarily introduced to the coolant buffer tank 13 and mixed with the circulating coolant to supply to the second heat exchanger 212. The amount of coolant in the system is indicated by a level indicator 301, and if the coolant amount decreases, a second coolant flow rate control valve 22 is opened to add more coolant.

If some of the coolant is vaporised by heat exchange with BOG in the heat exchanger 212, the pressure of the gas phase portion in the coolant buffer tank 13 is boosted by the second coolant delivery channel 216, and the gas phase portion of the coolant is pushed up by the liquid phase portion of the coolant from the lower portion of the coolant buffer tank 13. The pushed up coolant is introduced by the second coolant return channel 215 to the second heat exchanger 212. Thus, coolant can be transferred between the coolant buffer tank 13 and the second heat exchanger 212 without using motive force such as a pump.

A first coolant flow rate control valve 21 is arranged in the second coolant delivery channel 216. The first coolant flow rate control valve 21 is in a fully open state during normal operation.

If the pressure of the BOG in the second heat exchanger 212 drops due to too much BOG being condensed by the second heat exchanger 212 or the like, the pressure in the second heat exchanger 212 becomes a negative pressure relative to atmospheric pressure. As a result, contamination or damage to the second heat exchanger 212 may occur due to air mixing with the BOG in the second heat exchanger 212.

To correct this problem, the pressure of the BOG in the second heat exchanger 212 is detected by a first pressure indicator controller 304, and if the pressure on the BOG side detected by an arithmetic logic unit 303 is judged to be lower than a threshold value, the first coolant flow rate control valve 21 is closed to control the pressure.

Although the first pressure indicator controller 304 is arranged on the second exhaust pipe 214, the first pressure indicator controller 304 can detect the pressure in the second heat exchanger 212 because the pressure of the second exhaust pipe 214 is equivalent to the pressure in the second heat exchanger 212.

By controlling the first coolant flow rate control valve 21 to close, the boil-off gas generated by heat exchange in the second heat exchanger 212 accumulates in the upper portion of the second heat exchanger 212, and the pressure thereof returns the liquid coolant to the coolant buffer tank 13. This can end heat exchange in the second heat exchanger 212, stopping any further condensation of BOG, and can make the pressure of the BOG in the second heat exchanger 212 a negative pressure. The liquid level of the coolant in the second heat exchanger 212 drops when the liquid phase portion of the coolant in the second heat exchanger 212 is refluxed by the second coolant return channel to the coolant buffer tank 13. As a result, the heating surface area between the BOG and the liquid-phase coolant in the second heat exchanger 212 is reduced, which can minimise the phenomenon of over-cooling the BOG. In the case that the temperature has risen in the second heat exchanger 212, the opening of the first coolant flow rate control valve 21 can be increased to increase the liquid level of the coolant and lower the BOG temperature in the second heat exchanger 212.

The temperature of the second heat exchanger 212 may be measured by detecting the wall temperature of the second heat exchanger 212 or the temperature of the coolant inside, or may be learned by detecting the temperature of the waste nitrogen gas expelled from the second heat exchanger 212.

The coolant must operate at a temperature that does not solidify the BOG in the second heat exchanger 212, and pressure control considering the gas-liquid equilibrium of the coolant is advantageous for controlling the temperature of the coolant. For this purpose, a coolant pressure control valve 25 is opened and closed by a first pressure indicator controller 302 for

measuring and adjusting the pressure of the first cooling supply channel 115 so as to control the operating pressure of the second heat exchanger 212.

The coolant pressure control valve 23 is opened and closed by a third pressure indicator controller 305 so as to control the pressure of the BOG in the second heat exchanger 212.

5 Other embodiments

Although the first condenser 111 and the second condenser 211 may be arranged in parallel as shown in FIG. 1, as another embodiment, the second condenser 211 may be arranged lower than the first condenser 111. In this case, the first gas supply section 114 is a gas circulating section positioned between the first condenser 111 and the second condenser 211.

As another embodiment, the first coolant flow rate control valve 21 may be arranged on the second coolant return channel 215. In this case, the second coolant flow rate control valve 21 is controlled to close if the temperature in the second heat exchanger 212 drops below a desired temperature, and to open if the temperature rises above the desired temperature. As described above, the first coolant flow rate control valve 21 can be controlled to quickly adjust the temperature and effectively recondense BOG in the case that the heat quantity of the BOG fluctuates greatly.

Embodiment 2

20 The LNG storage system 2 of Embodiment 2 will be described referring to FIG. 2. Elements labelled with the same reference numerals as the BOG recondenser 1 of Embodiment 1 have the same function and will not be described again.

The LNG storage system 2 of Embodiment 2 has an LNG tank 33 for receiving transferred LNG, and an LNG buffer tank 12 for receiving the BOG in the LNG tank. The BOG in the LNG tank 33 is temporarily collected in the LNG buffer tank 12, and subsequently recondensed by the LNG recondenser 1 of Embodiment 1. The recondensed BOG recondensed and collected in the LNG buffer tank 12 is returned to the LNG tank 33 using a pump. When recondensed BOG is received from the LNG buffer tank 12, the volume of the liquid phase (LNG) in the LNG tank 33 is increased, and increases the pressure of the gas-phase (BOG) portion. In the case that the pressure in the LNG tank 33 is greater than a predetermined threshold value (for example, 1.1 bar), control may be exercised to receive the BOG in the LNG tank 33 in the LNG buffer tank 12.

Example 1

The pressure (barA), the temperature (°C), the flow rate (kg/h), the methane concentration (wt%), and the nitrogen concentration (wt%) in each section were simulated to verify when LNG having 80 wt% of methane and 20 wt% of nitrogen was stored as a raw material using the LNG storage system according to Embodiment 1. Liquid nitrogen was used as the coolant.

Results

When BOG of LNG (-150°C and 1.2 barA) was supplied at a flow rate of 11,740 kg/h from the LNG tank to the LNG buffer tank 12, the results shown in Table 1 were obtained for the pressure (barA), the temperature (°C), the flow rate (kg/h), the methane concentration (wt%), and the nitrogen concentration (wt%) in sections A-F and a-e in FIG. 3.

Sections A-F in FIG. 3 are the locations used to measure the temperature and the like of BOG, and sections a-e in FIG. 3 are the locations used to measure the temperature and the like of nitrogen. The locations of sections A-F and a-e in FIG. 3 are as follows.

A is located just in front of where BOG is introduced from the LNG tank (not shown) to the LNG buffer tank 12. The measurement result at location A is equivalent to the measurement result at the location in the BOG draw-off pipe 11 (shown as (A) in FIG. 3).

B is located on the first gas supply section 114 between the first condenser 111 and the second condenser 211.

C is located on the first return pipe 113 between the first condenser 111 and the LNG buffer tank 12.

D is located on the second exhaust pipe 214 at the upper portion exit of the second condenser 211.

E is located on the second return pipe 213 between the second condenser 211 and the LNG buffer tank 12.

F is located at the bottom exit of the LNG buffer tank 12 between the LNG buffer tank 12 and the LNG tank (not shown).

a is located just in front of where the coolant liquid nitrogen is introduced to the coolant buffer tank 13, between the coolant buffer tank 13 and the coolant flow rate control valve 22 arranged in front of the coolant buffer tank 13.

b is located on the second coolant return channel 215 between the coolant buffer tank 13 and the second heat exchanger 212.

c is located on the second coolant delivery channel 216 between the second heat exchanger 212 and the first coolant flow rate control valve 21.

d is located on the first coolant return channel 115 between the coolant buffer tank 13 and the first heat exchanger 112.

e is located at the exit of the first heat exchanger 112.

5 TABLE 1

	Pressure	Temperature	Mass flow	Methane	Nitrogen
	MPaA	deg.C	kg/h	wt %	wt %
A	1.20	-150.0	11,740	80.00	20.00
B	1.13	-162.1	10,547	77.85	22.15
C	1.20	-162.1	1,202	98.88	1.12
D	1.06	-182.0	220	6.49	93.51
E	1.20	-182.0	10,317	79.37	20.63
F	1.20	-179.9	11,520	81.40	18.60
a	3.80	-196.0	25,524	0.00	100.00
b	3.80	-186.0	104,483	0.00	100.00
c	3.80	-182.8	104,483	0.00	100.00
d	3.80	-182.8	25,524	0.00	100.00
e	3.70	-152.0	25,524	0.00	100.00

Based on the results of Example 1, BOG of LNG can be recondensed with high heat efficiency by using both the latent heat and the sensible heat of liquid nitrogen comprising a coolant and without using a compressor. The concentration of nitrogen in LNG was 20.0 wt% when BOG was introduced from the LNG tank to the LNG buffer tank 12, but had reduced to 1.1 wt% when the BOG was returned from the first condenser 111 to the LNG buffer tank 12 (C in FIG. 3). The nitrogen concentration rose slightly to 20.6 wt% when BOG was returned from the second condenser 211 to the LNG buffer tank 12 (E in FIG. 3), but had fallen to 18.6 wt% when BOG was returned from the LNG buffer tank 12 to the LNG tank (F in FIG. 3). Therefore, nitrogen in BOG of LNG could be reduced in the present example.

KEY TO REFERENCE NUMERALS

- 1 BOG recondenser
- 11 BOG draw-off pipe
- 12 LNG buffer tank
- 5 13 Coolant buffer tank
- 21 First coolant flow rate control valve
- 22 Second coolant flow rate control valve
- 23 Exhaust pressure control valve
- 25 Coolant pressure control valve
- 10 33 LNG tank
- 111 First condenser
- 112 First heat exchanger
- 113 First return pipe
- 114 First gas supply section
- 15 115 First coolant return channel
- 116 First coolant delivery channel
- 211 Second condenser
- 212 Second heat exchanger
- 213 Second return pipe
- 20 214 Second exhaust pipe
- 215 Second coolant return channel
- 216 Second coolant delivery channel
- 301 Level indicator
- 302 First pressure indicator controller
- 25 303 Arithmetic logic unit
- 304 Second pressure indicator controller
- 305 Third pressure indicator controller

Claims

1. BOG recondenser for recondensing boil-off gas (BOG) vaporised from LNG in an LNG buffer tank, characterized in that:
- 5 - a BOG draw-off pipe for drawing BOG from the LNG buffer tank,
- a first condenser for condensing at least some of the BOG delivered by the BOG draw-off pipe,
- a first gas supply section for supplying at least some of the gas in the first condenser from the first condenser to a second condenser,
- 10 - a first return pipe for returning at least some of the recondensed BOG in the first condenser from the first condenser to the LNG buffer tank,
- a second return pipe for returning the recondensed BOG in the second condenser from the second condenser to the LNG buffer tank, and
- a second exhaust pipe for expelling at least some of the gas in the second condenser
- 15 from the second condenser,
- are provided;
- the first condenser has a first heat exchanger;
- the second condenser has a second heat exchanger; and
- at least some of the coolant exchanging heat with the BOG in the second condenser in the
- 20 second heat exchanger is made to also exchange heat with the BOG in the first condenser in the first heat exchanger.
2. BOG recondenser according to Claim 1, characterized in that the second heat exchanger is a latent heat exchanger for exchanging heat between the latent heat of the
- 25 coolant and the heat quantity of the BOG in the second condenser, and
- the first heat exchanger is a sensible heat exchanger for exchanging heat between the sensible heat of the coolant and the heat quantity of the BOG in the first condenser.
3. BOG recondenser according to Claim 1 or Claim 2, characterized in that an opposite
- 30 end of the BOG draw-off pipe from the first condenser is disposed lower than the first heat exchanger;
- an opposite end of the first return pipe from the first condenser is disposed lower than the opposite end of the BOG draw-off pipe from the first condenser;

the opposite end of the first gas supply section from the first condenser is disposed higher than the first heat exchanger;

the opposite end of the first gas supply section from the second condenser is disposed lower than the second heat exchanger; and

5 the opposite end of the second return pipe from the second condenser is disposed lower than the opposite end of the first gas supply section from the second condenser.

4. BOG recondenser according to any one of Claims 1 to 3, characterized in that the second condenser is provided with a second exhaust pipe for drawing gas in the second
10 condenser, and an exhaust pressure control valve for exercising control such that the pressure in the second exhaust pipe is a predetermined value or lower; and the second exhaust pipe is disposed higher than the second heat exchanger.

5. BOG recondenser according to Claim 1 or Claim 2, characterized in that the second
15 heat exchanger is provided with:

- a second coolant delivery channel for drawing the coolant from the second heat exchanger,
- a coolant buffer tank for collecting a coolant delivered via the second coolant
20 delivery channel,
- a second coolant return channel for returning at least some of the liquid phase of the coolant in the coolant buffer tank to the second heat exchanger,
- and a second coolant flow rate control valve for controlling the circulation amount of the coolant.

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6. BOG recondenser according to any one of Claims 1 to 3, characterized in that a first coolant return channel for drawing at least some of the gas phase of the coolant in the coolant buffer tank to the first heat exchanger, is also provided.

30 7. BOG recondenser according to any one of Claims 1-4, characterized in that the coolant is liquid nitrogen and/or liquid air.

8. LNG storage system, provided with the BOG recondenser according to any one of Inventions 1 to 7, an LNG tank for storing LNG, an LNG tank BOG exhaust pipe for

introducing BOG in the LNG tank to the LNG buffer tank, and an LNG buffer tank LNG exhaust pipe for delivering at least some of the liquid phase of the LNG in the LNG buffer tank into the LNG tank.