BOG Recondenser and LNG Storage System Provided with Same

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

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 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).

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 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).

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

PATENT LITERATURE 3 International Patent Publication No. 2011/064605

SUMMARY

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.

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.

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 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 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 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 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 disclosure 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.

In a first aspect, the present disclosure provides 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 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, 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; 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.

In a second aspect, the present disclosure provides a BOG storage system, provided with the BOG recondenser according to the first aspect, 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.

Disclosure1

The BOG recondenser according to an embodiment of the present disclosure 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 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,
- 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;
- 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 disclosure does not require the expensive rotating machine of a compressor and requires no troublesome compressor maintenance. The BOG recondenser according to the present disclosure can use the cold of the coolant effectively and obtain high heat exchange efficiency because the coolant used in the second heat exchanger isalso used in the first heat exchanger.

According to the present disclosure, 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 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.

The BOG recondenser according to the present disclosure 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 disclosure may be installed in parallel in an upper portion of the LNG buffer tank. In this case, the first gas supply section 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 disclosure 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.

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

Disclosure 2

In the BOG recondenser according to an embodiment of the present disclosure, the second heat exchanger is a latent heat exchanger for exchanging heat between the latent heat of the 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 disclosure, 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 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 disclosure, 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 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 disclosure, which uses latent heat and sensible heat separately, is especially 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 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 BOG tends to change to a higher temperature.

In such a case, the present disclosure, 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 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 disclosure 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.

Disclosure 3

In the BOG recondenser according to an embodiment of the present disclosure, 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 disclosure, 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.

Disclosure 4

In the BOG recondenser according to an embodiment of the present disclosure, 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

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 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 LNG buffer tank, which improves the quality of the heat quantity of LNG in the LNG buffer tank.

Disclosure 5

In the BOG recondenser according to an embodiment of the present disclosure, the second heat exchanger may be provided with a second coolant delivery channel for drawing the coolant 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.

Disclosure 6

In the BOG recondenser according to an embodiment of the present disclosure, 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.

Disclosure 7

In the BOG recondenser according to an embodiment of the present disclosure, 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

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.

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 exchanging heat with liquid air, and liquefied liquid nitrogen may be used to exchange heat with BOG.

Disclosure 8

The LNG storage system according to an embodiment the present disclosure is provided with the BOG recondenser according to any one of disclosures 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.

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 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 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;

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