BOG Recondenser and LNG Supply System Provided with Same

The present invention relates to a BOG recondenser for recondensing BOG of LNG and an LNG supply 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) that has been vaporised, for example, by natural external heat input.

A method is known for returning BOG generated from a storage tank for storing LNG to an LNG buffer tank after recondensing by heat exchange with a very low temperature coolant such as liquid nitrogen or liquid air (for example, Patent Publication No. 2002-295799).

In a BOG recondenser using liquid nitrogen as a coolant, heat exchange between the liquid nitrogen and BOG generated from an LNG buffer tank usually takes place in a single recondenser. This has had the problem that the relatively high temperature BOG and the very low temperature liquid nitrogen exchange heat very rapidly, and methane, the main component in BOG, and impurities solidify and obstruct the piping.

Over-cooling BOG in a recondenser unit produces a negative pressure in the recondenser unit, which risks deforming or damaging the recondenser unit. Although the recondenser unit must have a very strong pressure-resistant structure to reduce deformation or damage, designing such a structure is not easy in terms of choice of materials and complexity of structure.

In view of this situation, an objective of the present invention is to provide an LNG recondenser and an LNG recondensing method that reduce obstruction of piping in the recondenser caused by methane, the main component, and impurities.

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, provided with:

- a BOG draw-off pipe for drawing BOG from the LNG buffer tank,
- a first condenser for cooling BOG fed by the BOG draw-off pipe to a first temperature,
- a first gas supply section for drawing gas in the first condenser from the first condenser,
- a first return pipe for returning LNG in the first condenser from the first condenser to the LNG buffer tank,
- a second condenser for cooling BOG fed by the first gas supply section to a second temperature lower than the first temperature, and
- a second return pipe for returning LNG in the second condenser from the second condenser to the LNG buffer tank;

and the BOG recondenser is also provided with:

- cooling control means for controlling the feed amount and/or temperature of a first coolant fed to the first condenser and/or a second coolant fed to the second condenser.

BOG of LNG contains mainly methane and nitrogen as components, and a low temperature coolant such as liquid nitrogen or liquid air, for example, is required to condense the methane. Because these coolants cannot attain a lower temperature than the solidifying point of methane, however, introducing BOG directly to a second condenser using liquid nitrogen or liquid air as the coolant can lead to solidification of methane.

To mitigate solidification of methane in the second condenser, some of the methane in the BOG in the first condenser is condensed to increase the concentration of nitrogen in the BOG introduced to the second condenser. This can effectively lower the freezing point of methane, and as a result, easily prevent solidification of methane in the second condenser. Specifically, methane does not solidify in the second condenser even if BOG is cooled to the second temperature.

According to this aspect of the present invention, BOG is cooled to the first temperature in the first condenser. The first temperature is a higher temperature than the second temperature, and therefore does not risk solidifying the methane in the first condenser.

Thus, according to this aspect of the present invention, BOG can be recondensed without solidifying methane in either the first condenser or the second condenser.

In the BOG recondenser according to an aspect of the present invention, the first condenser may have a first heat exchanger, the second condenser may have a second heat exchanger, and at least some of the coolant drawn from the second heat exchanger may be introduced to the first heat exchanger.

Although different coolants may be used in the first heat exchanger and the second heat exchanger, the coolant used for heat exchange in the second heat exchanger may be introduced to the first heat exchanger and reused for heat exchange. According to such a configuration, after passing through the second heat exchanger, the coolant exchanges heat with the BOG in the second condenser to increase the temperature to a predetermined temperature. The coolant is introduced to the first heat exchanger and exchanges more heat with the BOG in the first condenser to further increase the temperature.

Thus, the temperature of the first heat exchanger is inevitably higher than the temperature of the second heat exchanger, which facilitates temperature control. The cold of the coolant can also be used more effectively.

The cooling control means may be provided with:

a coolant buffer tank for collecting coolant,

a level indication controller and a second coolant flow rate control valve for controlling the introduced amount of the coolant supplied to the coolant buffer tank,

a circulation route for returning coolant from the coolant buffer tank through the second heat exchanger of the second condenser to the coolant buffer tank,

a first coolant flow rate control valve arranged on the circulation route between the second heat exchanger and the coolant buffer tank,

a first coolant return route for feeding the coolant from the coolant buffer tank to the first heat exchanger of the first condenser,

a second pressure indicator controller for measuring the pressure of exhaust gas containing nitrogen gas expelled from the second condenser, and

a controller for controlling the coolant flow rate control valve on the basis of the measurement of the second pressure indicator controller.

The coolant control means may also be provided with a first coolant pressure control valve arranged on the first coolant return channel.

The coolant pressure control valve may control the valve opening position so that coolant is fed at a certain pressure (or a pressure in a certain range or a predetermined pressure). The valve opening position is controlled on the basis of the measurement of pressure measured by a first pressure indicator controller arranged on the first coolant return channel.

The coolant fed to the second heat exchanger of the second condenser is fed from the liquid phase portion of the coolant in the coolant buffer tank.

The coolant fed to the first heat exchanger of the first condenser is fed from at least some of the gas phase portion of the coolant in the coolant buffer tank.

The pressure in the second condenser may drop to lower than atmospheric pressure (a negative pressure) if the amount of BOG introduced to the second condenser rapidly decreases or too much coolant is supplied to the second heat exchanger during heat exchange between the BOG and the coolant in the second heat exchanger. The drop in pressure is especially marked in the case that a coolant having a great temperature difference from BOG is used, such as liquid nitrogen or liquid air. When the pressure in the second condenser is lower than atmospheric pressure, external air is mixed in and risks reacting explosively with BOG and/or LNG and causing deformation of the condenser itself and damage to the recondenser.

With this aspect of the present invention, the amount of coolant introduced to the second heat exchanger can be adjusted according to the pressure in the second heat exchanger to control the

phenomenon of the second condenser becoming a negative pressure. Specifically, if the pressure measured by the second pressure indicator controller arranged on the second exhaust pipe is lower than a predetermined first pressure threshold value (P1), the opening of the second coolant flow rate control valve may be decreased to adjust the pressure, and if the measured pressure is higher than a second threshold value (P2; P2 is a pressure higher than P1), the opening of the second coolant flow rate control valve may be increased to adjust the pressure.

Closing or decreasing the opening of the second coolant flow rate control valve increases the pressure of the coolant in the second heat exchanger. As a result, coolant in the second heat exchanger flows back in the second coolant delivery channel in the direction from the second heat exchanger to the coolant buffer tank. This can decrease the heating surface area between the coolant and the BOG in the second heat exchanger to restrain heat exchange. This restraint can prevent producing a negative pressure in the second condenser.

Thus, according to the present invention, adjusting the opening of the coolant flow rate control valve can control the phenomenon of the second condenser becoming a negative pressure, and restrain explosion and deformation of the condenser caused by mixture of external air or the like. Preventing admixture of external air can also restrain the mixed in external air condensing and increasing impurities in the LNG.

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

The coolant preferably has a lower liquefaction temperature than the condensation temperature of BOG. Examples of fluids that have a lower liquefaction temperature than the condensation temperature of BOG are liquid nitrogen and liquid air. 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.

After liquid nitrogen has exchanged heat with BOG, the liquid nitrogen may be reused by exchanging heat with liquid air to cool and reliquefy.

The coolant may be a mixture of liquid nitrogen and liquid air.

In the case that the coolant in the BOG recondenser according to an aspect of the present invention is nitrogen, the BOG recondenser may have a pressure control nitrogen introduction route for introducing the nitrogen gas in the first coolant delivery channel to the second condenser if the pressure of the second condenser drops below a predetermined lower limit value.

According to this aspect of the present invention, if the pressure in the second condenser drops below a predetermined lower limit value (P_{TH}; for example, 1.03 bar), nitrogen gas used as the coolant may be introduced into the second condenser to prevent the second condenser becoming a negative pressure. Such a negative pressure prevention measure may be provided alone, or after providing the negative pressure prevention measure indicated in the Invention 3, the present measure may be provided as a supplementary measure if the pressure is lower than the lower limit pressure even after applying the measure in the Invention 3. In this case, the lower limit value P_{TH} is a lower pressure value than the first pressure threshold value P1 in the

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 6, 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 to 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 BOG recondenser of Embodiment 2;

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

FIG. 4 is a diagram showing a configuration example of the LNG storage system of Embodiment 4; and

FIG. 5 is a diagram showing data measurement locations and the configuration of the BOG recondenser of Embodiment 1.

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. 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 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 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 exchanges heat with coolant in the first heat exchanger 112 to cool to a first temperature (for example, -152°C) and recondense. The first temperature is a temperature at which some BOG recondenses, and may be any temperature that does not cause rapid solidification of methane; for example, a range from -162°C to -150°C.

The first condenser 111 and the second condenser 211 may be installed parallel to an upper portion of the LNG buffer tank 12 as shown in FIG. 1. In this case, the first gas supply section 114 may be a gas supply pipe for introducing gas drawn from the first condenser 111 to the second condenser 211.

The first condenser 111 and the second condenser 211 in the present invention may also be installed in series in an upper portion of the LNG buffer tank 12 (not depicted). In this case, the first gas supply section 114 is located in an intermediate area between the first condenser 111 and the second condenser 211.

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 and/or the second condenser is returned.

The BOG recondensed in the first condenser 111 is returned to the LNG buffer tank 12 via a first return pipe 113. The BOG introduced to the first condenser 111 that was not recondensed in the first condenser 111 is introduced by a first gas supply section 114 to the second condenser 211. The BOG introduced to the second condenser 211 contains more nitrogen components than the BOG in the LNG buffer tank 12 due to passing through the first condenser 111.

At least some of the BOG introduced to the second condenser 211 exchanges heat with the coolant in the second heat exchanger 212 to cool to a second temperature (for example, -185°C) and recondense. The second temperature is lower than the first temperature, and may be any temperature capable of sufficiently recondensing BOG; for example, a range of -190°C to -182°C. The BOG in the second heat exchanger 212 contains many nitrogen components, and therefore will not freeze even at a temperature lower than -182°C, which is the freezing point of pure LNG, due to an effect depressing the freezing point of LNG. The recondensed BOG is returned to the LNG buffer tank 12 via a second return pipe 213.

The coolant used in the second heat exchanger 212 is introduced from the second coolant buffer tank 501 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. After heat exchange with BOG at the second temperature in the second heat exchanger 212, the temperature of the coolant rises to the first temperature, which is higher than the second temperature. The coolant at the first temperature exchanges heat with BOG in the first heat exchanger 112 in the first condenser 111.

The coolant may be any coolant that is a liquid or gas state at the first temperature and the second temperature; for example, nitrogen, air, or a mixture of nitrogen and air may be used. In the case that nitrogen is used as the coolant, the nitrogen coolant is introduced to the second heat exchanger 212 in a liquid state. Following heat exchange with the BOG in the second heat exchanger 212, the liquid nitrogen is introduced to the first heat exchanger 112 via the second coolant delivery channel 216. 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. 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.

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. Liquid nitrogen may be used as the coolant, and although 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 second 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

Claims

1. 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 cooling BOG fed by the BOG draw-off pipe to a first temperature, the first condenser having a first heat exchanger,

a first gas supply section for supplying gas in the first condenser to a second condenser,

a first return pipe for returning LNG in the first condenser from the first condenser to the LNG buffer tank,

the second condenser for cooling BOG fed by the first gas supply section to a second temperature lower than the first temperature, the second condenser having a second heat exchanger, and

a second return pipe for returning LNG in the second condenser from the second condenser to the LNG buffer tank

are provided;

the BOG recondenser is also provided with cooling control means for controlling the feed amount and/or temperature of a first coolant fed to the first condenser and/or a second coolant fed to the second condenser, characterized in that at least some of the second coolant drawn from the second heat exchanger is introduced to the first heat exchanger, and the cooling control means is provided with:

a coolant buffer tank for collecting the at least some of the second coolant,

a level indication controller and a second coolant flow rate control valve for controlling the introduced amount of the at least some of the second coolant supplied to the coolant buffer tank,

a circulation route for returning a coolant from the coolant buffer tank through the second heat exchanger of the second condenser to the coolant buffer tank,

a first coolant flow rate control valve arranged on the circulation route between the second heat exchanger and the coolant buffer tank,

a first coolant return route for feeding the at least some of the second coolant from the coolant buffer tank to the first heat exchanger of the first condenser,

a pressure indicator controller for measuring the pressure of exhaust gas containing the nitrogen gas expelled from the second condenser, and

a controller for controlling the first coolant flow rate control valve on the basis of the measurement of the pressure indicator controller.

2. BOG recondenser according to Claim 1, characterized in that the second coolant is liquid nitrogen and/or liquid air.

3. BOG recondenser according to Claim 1, characterized in that in the case that the first coolant and the second coolant are nitrogen, the BOG recondenser has a pressure control nitrogen introduction route for introducing the nitrogen gas in a first coolant delivery channel to the second condenser if the pressure of the second condenser drops below a predetermined lower limit value.

4. LNG supply system provided with a LNG buffer tank, and
the BOG recondenser according to any one of Claims 1-3.