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(71) Applicant: **L'AIR LIQUIDE, SOCIETE ANONYME POUR L'ETUDE ET L'EXPLOITATION DES PROCEDES GEORGES CLAUDE** [FR/FR]; 75, Quai d'Orsay, 75007 PARIS (FR).

(72) Inventors: **HIROSE, Kenji**; c/o Air Liquide Global E&C Solutions Japan Ltd., 7-1-15, Goko-dori, Chuo-ku, Hyogo Prefecture, 651-0087, KOBE, Hyogo 651-0087 (JP). **TOMITA, Shinji**; c/o Air Liquide Global E&C Solutions Japan Ltd., 7-1-15, Goko-dori, Chuo-ku, Hyogo Prefecture, KOBE, Hyogo 651-0087 (JP). **NAGATA, Daisuke**; c/o Air Liquide Global E&C Solutions Japan Ltd., 7-1-15, Goko-dori, Chuo-ku, Hyogo Prefecture, KOBE, Hyogo 651-0087 (JP).

(74) Agent: **DE BEAUFORT, François-Xavier**; Intellectual Property Department, 75 Quai d'Orsay, 75321 PARIS Cedex 07 (FR).

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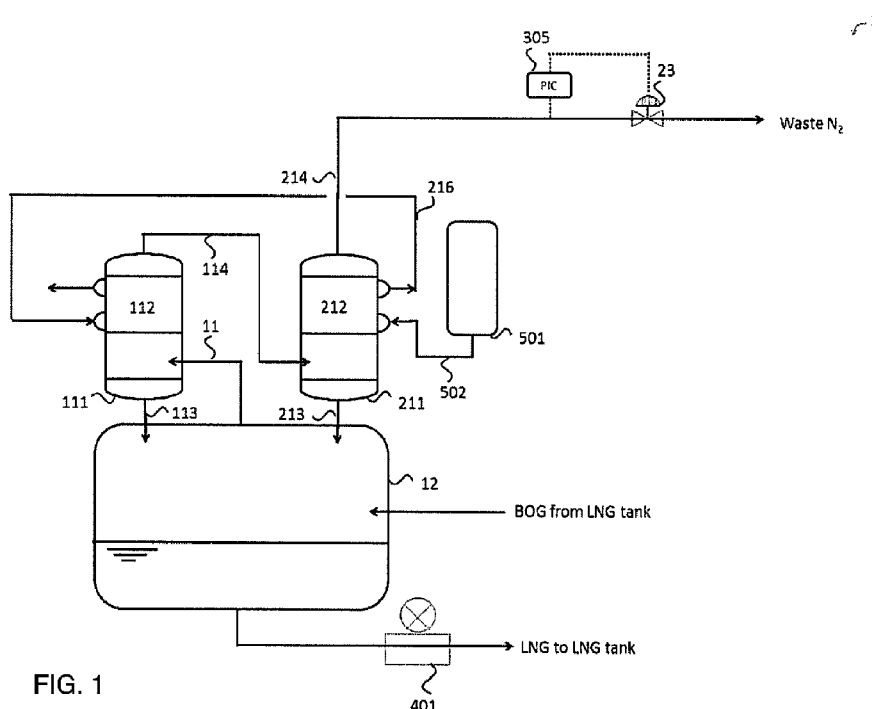


FIG. 1

(57) Abstract: PROBLEM TO BE SOLVED: To provide a BOG recondenser and an LNG supply system provided with an LNG buffer tank and the BOG recondenser, that reduce obstruction of piping in the recondenser caused by methane, the main component, and impurities. SOLUTION: The BOG recondenser 1 is a BOG recondenser for recondensing boil-off gas (BOG) vaporised from LNG in an LNG buffer tank 12 provided with a BOG draw-off pipe 11 for drawing BOG from the LNG buffer tank, a first condenser 111 for cooling BOG fed by the BOG draw-off pipe to a first temperature, a first gas supply section 114 for drawing gas from the first condenser 111, and a second condenser 211 for cooling BOG fed by the first gas supply section 114 to a second temperature lower than the first temperature; and the BOG recondenser 1 is also provided with cooling control means for controlling the feed amount and/or temperature of a first coolant fed to the first condenser 111 and/or a second coolant fed to the second condenser 211.



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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.

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) 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
10 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
15 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.

20 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
25 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
30 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
5 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
10 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.

15 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.

20 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
25 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
30 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,

5 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,

10 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.

15 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
20 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.

25 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
30 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

5 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

10 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

15 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.

20 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

25 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.

30 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

5 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 P_1 in the

The LNG storage system according to an aspect the present invention is provided with the BOG

10 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

15 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

20 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;

25 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

30 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
5 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)
10 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
15 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
20 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
25 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
30 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.

Embodiment 2

The BOG recondenser 2 of Embodiment 2 will be described with reference 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.

- 5 The coolant used in the first heat exchanger 112 and the coolant used in the second heat exchanger 212 may be different, as shown in FIG. 2. In this case, the temperature of the first coolant flowing into the first heat exchanger 112 is controlled to the first temperature, and the temperature of the second coolant flowing into the second heat exchanger 212 is controlled to the second temperature.
- 10 The first coolant is fed from a first coolant buffer tank 503 to the first heat exchanger 112 in the first condenser 111 via a first coolant channel 504. The first coolant may be controlled to a predetermined temperature by a temperature control mechanism (not shown) disposed in the first coolant buffer tank 503. The flow rate of the first coolant may be controlled by a flowmeter (not shown) disposed on the first coolant channel 504 so that the first heat exchanger 112 attains
- 15 the first temperature.

Similarly, the second coolant is fed from a second coolant buffer tank 501 to the second heat exchanger 212 in the second condenser 211 via a second coolant channel 502. The second coolant may be controlled to a predetermined temperature by a temperature control mechanism (not shown) disposed in the second coolant buffer tank 501. The flow rate of the second coolant

20 may be controlled by a flowmeter (not shown) disposed on the second coolant channel 502 so that the second heat exchanger 212 attains the second temperature.

Embodiment 3

- The BOG recondenser 3 of Embodiment 3 will be described with reference to FIG. 3. Elements labelled with the same reference numerals as the BOG recondenser 1 of Embodiment 1 or the
- 25 BOG recondenser 2 of Embodiment 2 have the same function and will not be described again. 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 as shown in FIG. 3.
- The coolant drawn from the second heat exchanger 212 is introduced by the second coolant delivery channel 216 to the coolant buffer tank 13. The liquid phase portion of the coolant
- 30 introduced to the coolant buffer tank 13 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. The gas phase portion of the coolant introduced to the coolant buffer tank 13 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. 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.

- 5 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 10 212, 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 15 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 20 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 25 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 30 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 to prevent the pressure of the BOG in the second heat exchanger 212 becoming 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 215 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 control the phenomenon of over-cooling the BOG. If the temperature rises in the second heat exchanger 212, the opening of the first coolant flow rate control valve 21 may 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.

Thus, the second 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.

The second coolant flow rate control valve 21 is arranged in the second coolant delivery channel 216. If the temperature of the second heat exchanger 212 drops below a predetermined temperature T1 (-182°C in the present embodiment) or the pressure in the second heat exchanger 212 drops below a predetermined pressure P1 (1.06 bar in the present embodiment), the second coolant flow rate control valve 21 may be closed or the opening thereof decreased to increase the pressure of the gas phase portion of the coolant in the second heat exchanger 212. This refluxes the gas phase portion of the coolant in the second heat exchanger 212 from the second coolant return channel 215 to the coolant buffer tank 13, and lowers the liquid level of the coolant in the second heat exchanger 212. 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

control the phenomenon of over-cooling the BOG. If the temperature rises in the second heat exchanger 212, the opening of the second coolant flow rate control valve 21 may be increased to raise the liquid level of the coolant and lower the BOG temperature in the second heat exchanger 212.

- 5 The predetermined pressure P1 may be any pressure greater than or equal to atmospheric pressure, and can restrain the pressure in the second condenser 211 dropping below atmospheric pressure and causing deformation or damage of the condenser.

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
10 be learned by detecting the temperature of the waste nitrogen gas expelled from the second heat exchanger 212.

If the pressure in the second condenser 211 reaches the lower limit value, which is even lower than the predetermined pressure P1 (the lower limit value P_{TH} ; the lower limit value P_{TH} is a lower pressure than P1), the coolant expelled from the first heat exchanger 112 (nitrogen gas in
15 the present embodiment) is introduced to the second condenser 212. P_{TH} may be any pressure lower than P1 and higher than atmospheric pressure, and is 1.03 bar in the present embodiment. The pressure in the second condenser 211 is detected by a pressure gauge arranged on the second exhaust pipe 214, and if the detected pressure is lower than P_{TH} , a fourth coolant flow rate control valve 24 is opened to introduce the nitrogen gas in the first coolant delivery channel
20 116 to the second condenser 211 via the second exhaust pipe 214. This can prevent the second condenser 211 becoming an even lower negative pressure.

Embodiment 4

The LNG storage system 4 of Embodiment 4 will be described referring to FIG. 4. Elements labelled with the same reference numerals as the BOG recondensers 1-3 of Embodiments 1-3
25 have the same function and will not be described again.

The LNG storage system 4 of Embodiment 4 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 BOG recondenser 1 of Embodiment 1. The recondensed BOG recondensed and collected
30 in the LNG buffer tank 12 is returned to the LNG tank 33 using a pump 401. 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. A pressure gauge (not shown) for measuring the pressure in the LNG tank may be disposed in the LNG tank 33, and may exercise control so that the BOG in the LNG tank 33 is received by the

LNG buffer tank 12 if the pressure in the LNG tank 33 is greater than a predetermined threshold value (for example, 1.1 bar).

Example 1

5 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 BOG recondenser 3 according to Embodiment 3. Liquid nitrogen was used as the coolant.

Results

10 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. 5.

Sections A-F in FIG. 5 are the locations used to measure the temperature and the like of BOG, and sections a-e in FIG. 5 are the locations used to measure the temperature and the like of
15 nitrogen. The locations of sections A-F and a-e in FIG. 5 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. 5).

20 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.

25 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).

30 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.

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

TABLE 1

	Pressure	Temperature	Mass flow	Methane	Nitrogen
	barA	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

10 Based on the results of Example 1, BOG of LNG could be recondensed in both the first condenser 111 and the second condenser 211 without causing methane to solidify. 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 the nitrogen concentration was 20.6 wt% when the BOG was returned from the second condenser 211 to the LNG buffer tank 12 (E in FIG. 5). Consequently,

15 the freezing point of methane was -182°C when the methane contained no nitrogen, but dropped to -186°C when the methane contained 20.6 wt% of nitrogen. Therefore, the methane did not freeze even after cooling to -182°C, and could be returned to the LNG buffer tank 12 in a liquid state.

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
	401	Pump

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 cooling BOG fed by the BOG draw-off pipe to a first temperature,
 - 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,
 - 10 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 tankare provided;
- 15 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.
2. BOG recondenser according to Claim 1, characterized in that the first condenser has a first heat exchanger;
 - 20 the second condenser has a second heat exchanger; and
 - at least some of the coolant drawn from the second heat exchanger is introduced to the first heat exchanger.
- 25 3. BOG recondenser according to Claim 2, characterized in that the cooling control means is 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,
 - 30 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 pressure indicator controller for measuring the pressure of exhaust gas containing the nitrogen gas expelled from the second condenser, and

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

4. BOG recondenser according to any one of Claims 1-3, characterized in that the coolant is liquid nitrogen and/or liquid air.

10

5. BOG recondenser according to any one of Claims 1-4, characterized in that in the case that the coolant is nitrogen, the BOG recondenser has 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.

15

6. LNG supply system provided with a LNG buffer tank, and the BOG recondenser according to any one of Claims 1-5.

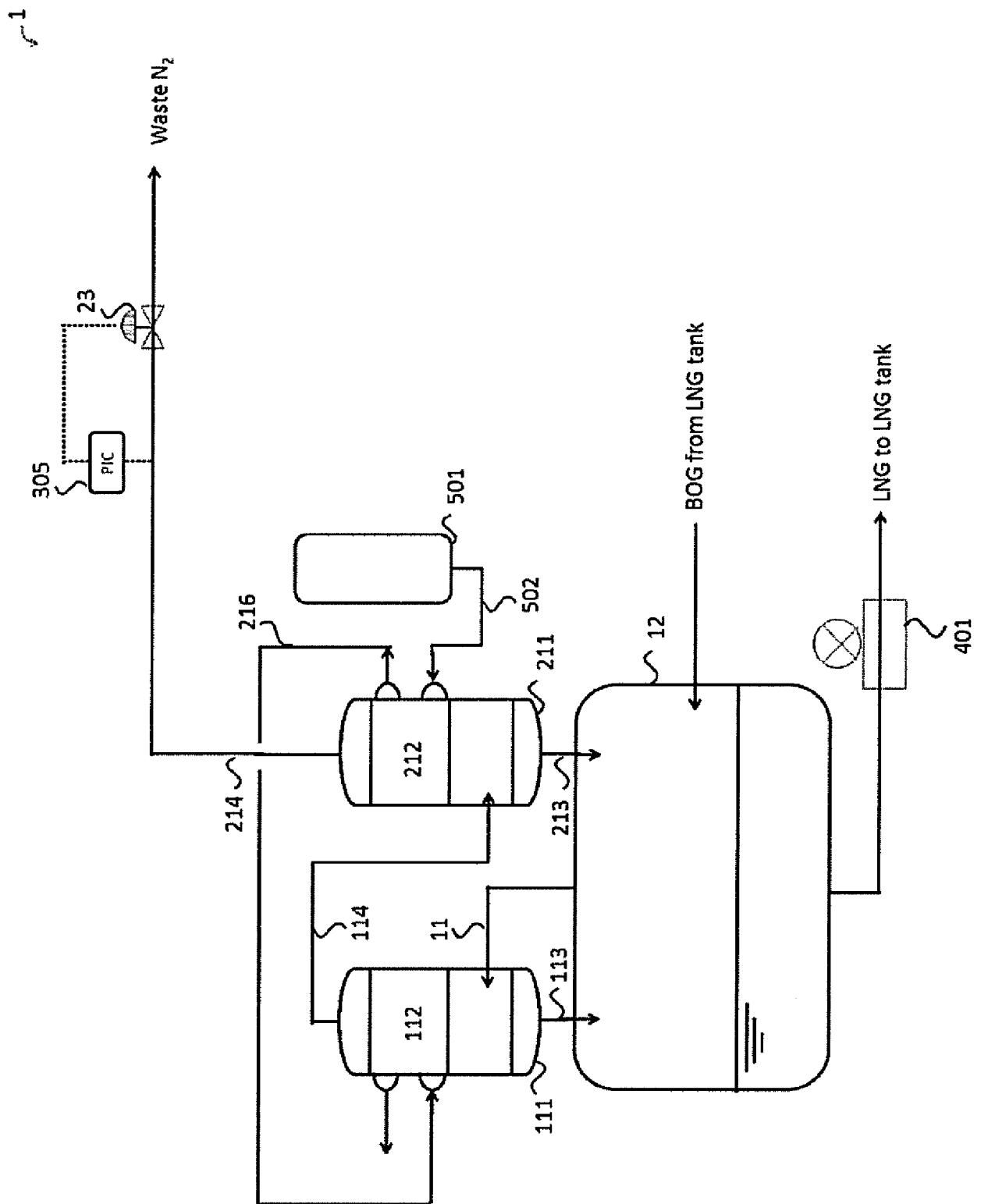


FIG. 1

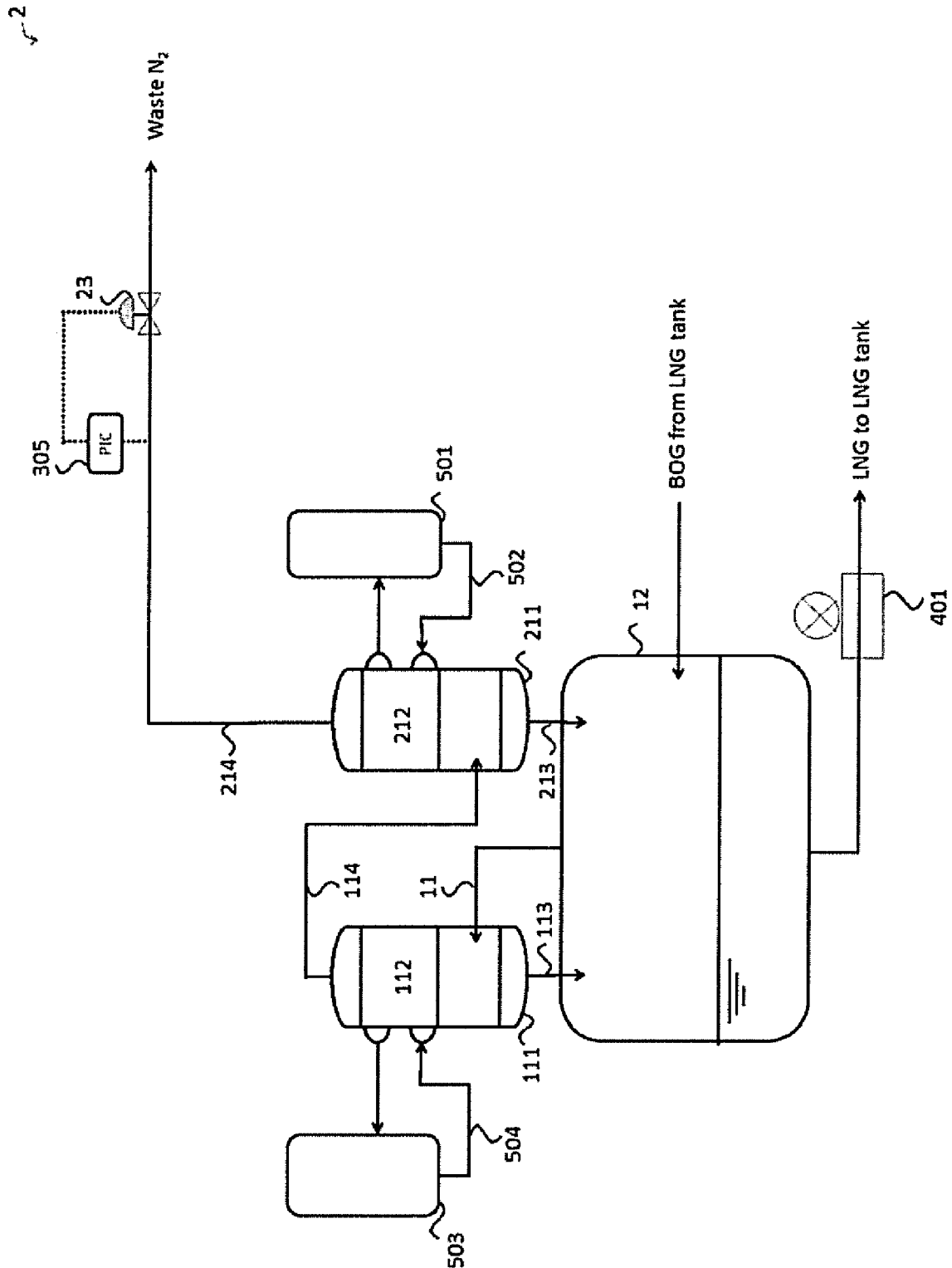


FIG. 2

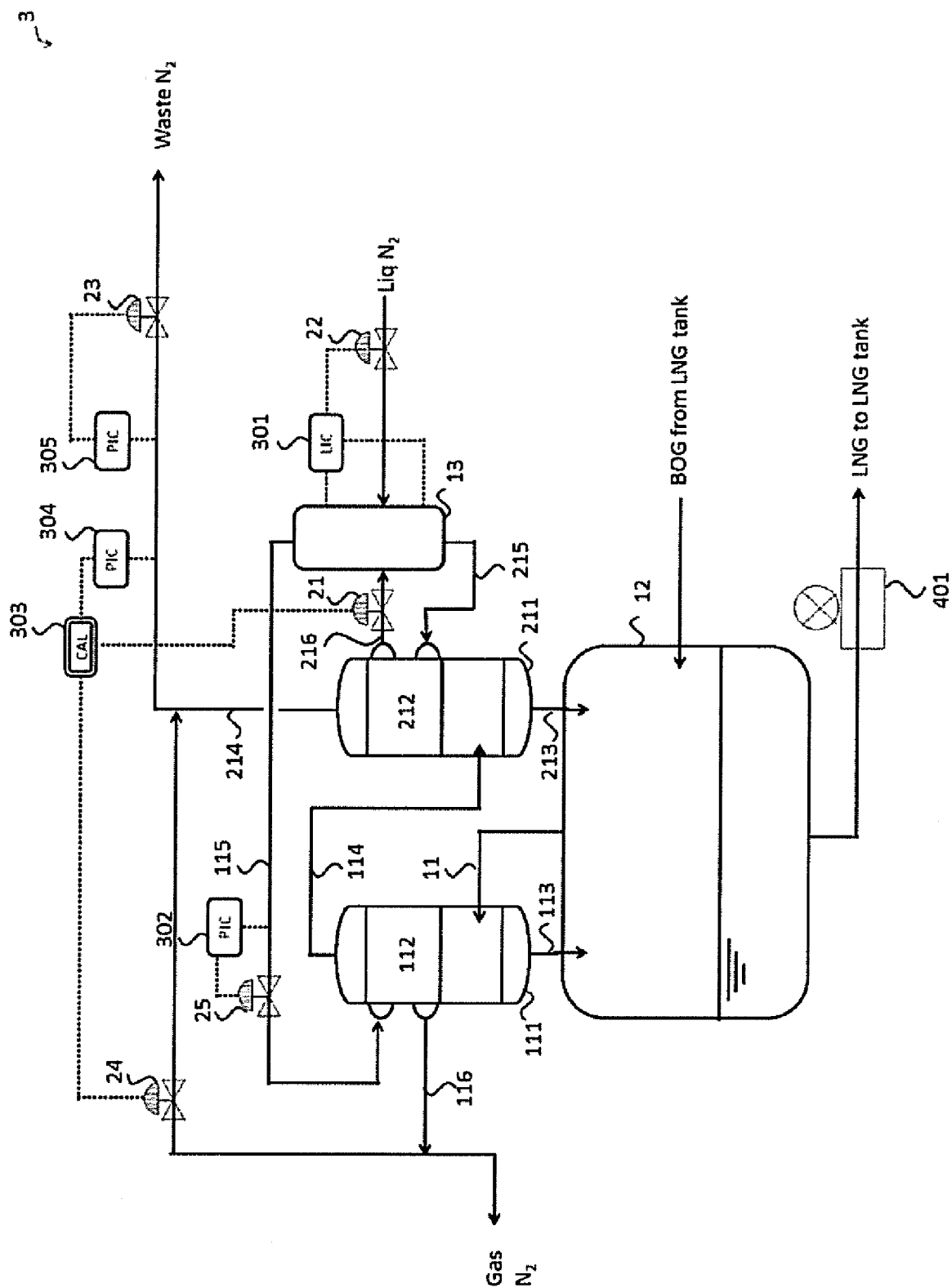


FIG. 3

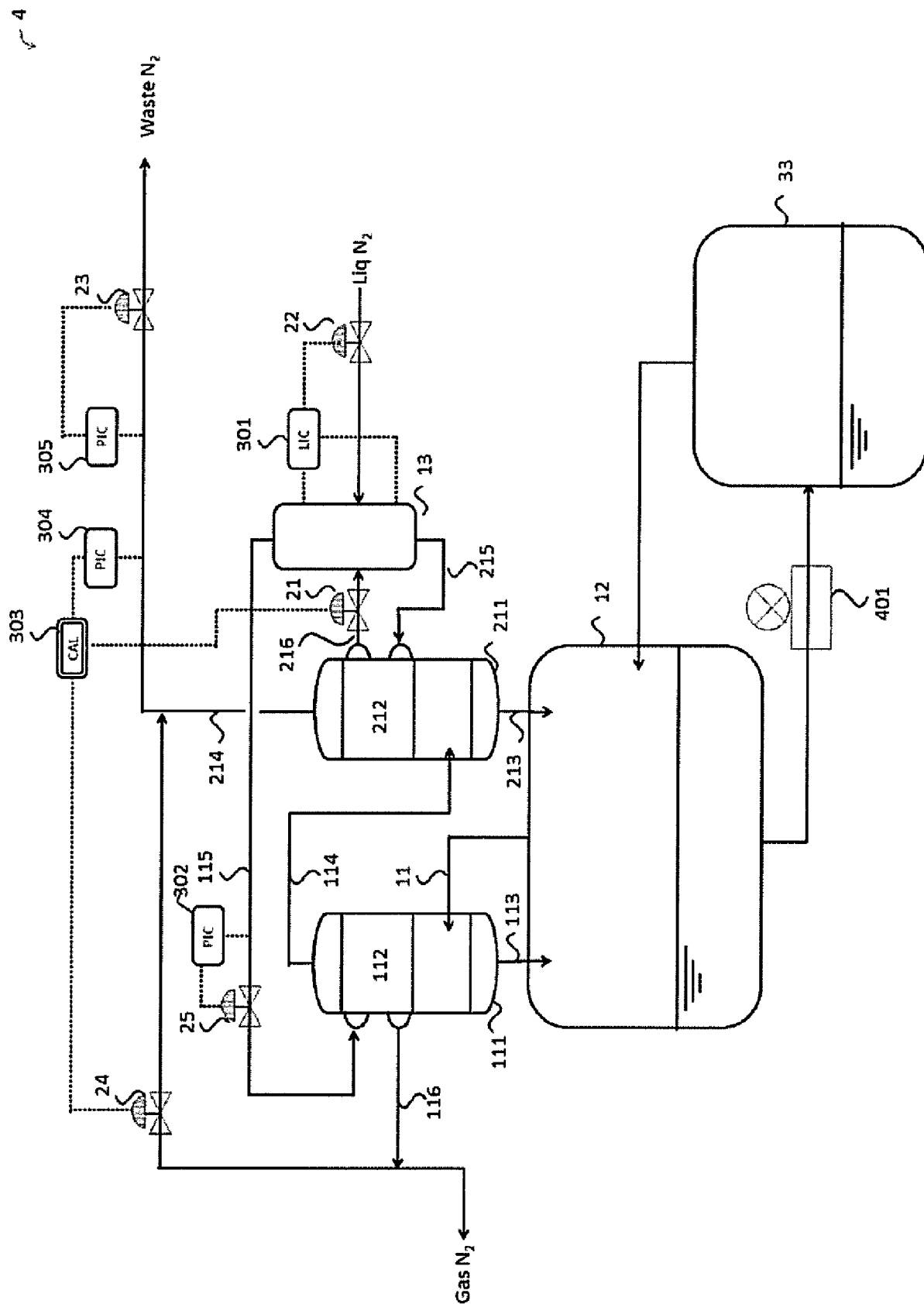


FIG. 4

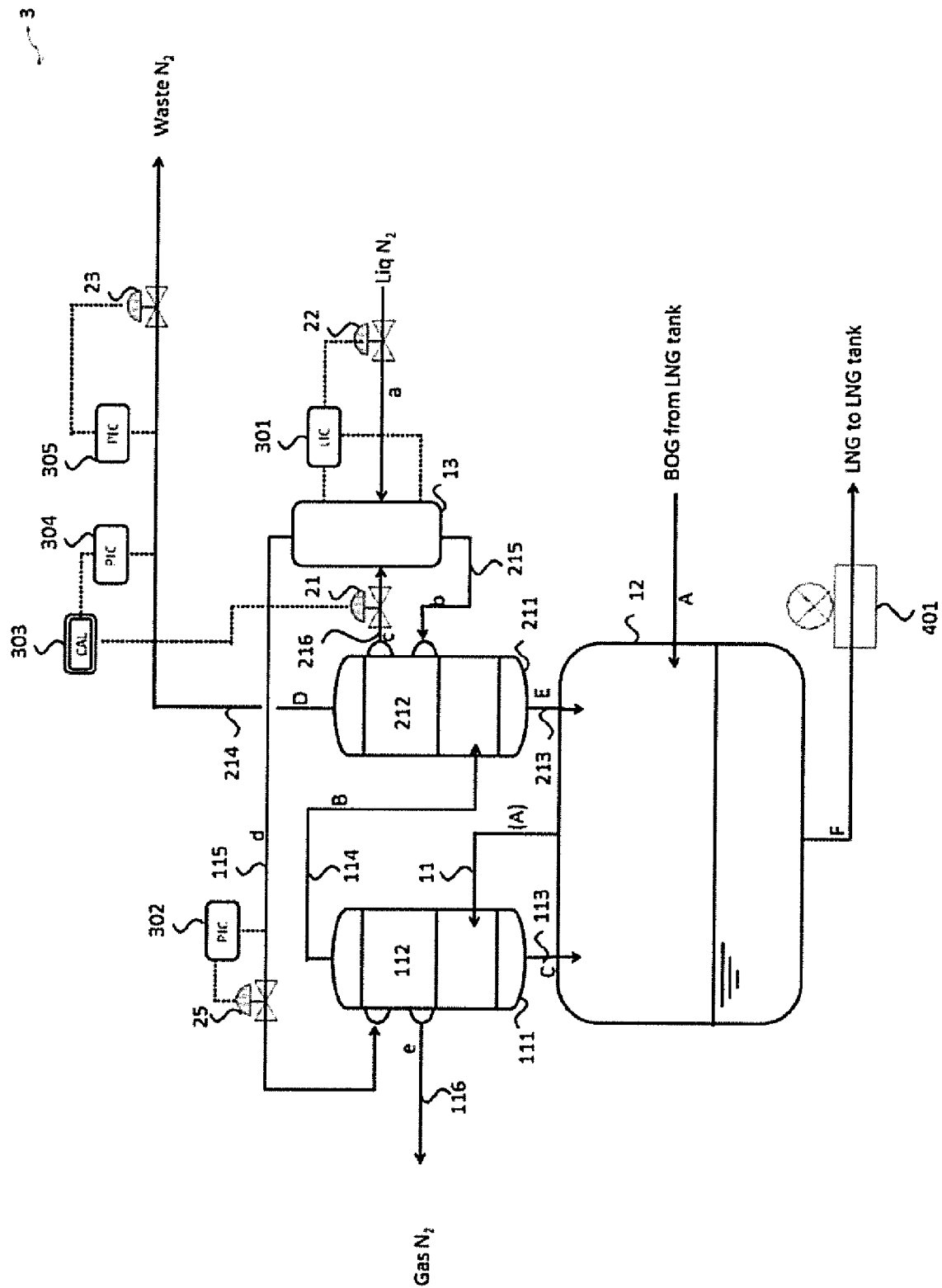


FIG.5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/080252

A. CLASSIFICATION OF SUBJECT MATTER
INV. F25J1/00 F25J1/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 6 209 350 B1 (KIMBLE III E LAWRENCE [US]) 3 April 2001 (2001-04-03) figures 1, 2 column 6, line 6 - column 8, line 11 table 1	1,2,6 3-5
X A	----- KR 2013 0080209 A (STX OFFSHORE & SHIPBUILDING CO [KR]) 12 July 2013 (2013-07-12) figure 2 paragraph [0017] - paragraph [0019] paragraph [0026] - paragraph [0058] ----- -/-	1,4,6 2,3,5



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search

29 January 2019

Date of mailing of the international search report

29/03/2019

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Karspeck, Sabine

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2018/080252

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 2018/096187 A2 (LAIR LIQUIDE SA POUR LETUDE ET LEXPLOITATION DES PROCEDES GEORGES CLAU) 31 May 2018 (2018-05-31)	1-4,6
A,P	figures 3, 4C page 16, line 19 - page 23, line 23 page 24, line 21 - page 28, line 7 -----	5
A	US 2012/060553 A1 (BAUER HEINZ [DE]) 15 March 2012 (2012-03-15) figure 1 paragraph [0004] paragraph [0006] paragraph [0022] - paragraph [0037] -----	1-6

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2018/080252

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6209350	B1	03-04-2001	AR 020936 A1 05-06-2002
		AU 1129900 A 15-05-2000	
		CA 2346966 A1 04-05-2000	
		CO 5100986 A1 27-11-2001	
		DZ 2921 A1 01-03-2004	
		EG 22284 A 31-12-2002	
		MY 115506 A 30-06-2003	
		NO 20011939 A 20-06-2001	
		PE 08262000 A1 04-10-2000	
		RU 2228486 C2 10-05-2004	
		TN SN99195 A1 31-12-2001	
		US 6209350 B1 03-04-2001	
		WO 0025060 A1 04-05-2000	

KR 20130080209	A	12-07-2013	NONE

WO 2018096187	A2	31-05-2018	NONE

US 2012060553	A1	15-03-2012	AR 082919 A1 16-01-2013
		AU 2011221424 A1 29-03-2012	
		BR PI1104609 A2 24-04-2013	
		CH 703773 A2 15-03-2012	
		CN 102410702 A 11-04-2012	
		DE 102010044869 A1 15-03-2012	
		US 2012060553 A1 15-03-2012	
