Gas liquefaction method and gas liquefaction device

The present invention relates to a gas liquefaction device and a gas liquefaction method, and in particular relates to a gas liquefaction device and a gas liquefaction method with which liquid nitrogen is obtained with a high efficiency, in a nitrogen gas liquefaction device which utilizes the coldness of liquefied natural gas.

Liquefied natural gas (NG) is stored as liquefied natural gas (LNG) for convenience of transport and storage, for example, and after vaporisation is used mainly for thermal power generation and as town gas. For this reason, techniques have been developed to utilize effectively the coldness of the LNG obtained during vaporisation.

Facilities for liquefying nitrogen gas or the like by utilizing the coldness of LNG generally employ a process in which nitrogen gas is compressed using a compressor, after which a heat exchanger is used to effect heat exchange with LNG, causing the LNG to increase in temperature and to vaporise, and liquefying the nitrogen gas.

For example, JP 2005-164150 discloses a method in which high-pressure nitrogen gas that has been compressed by means of a compressor is cooled using coldness released when LNG is caused to evaporate, after which the nitrogen gas is decompressed using a pressure reducing valve to obtain liquid nitrogen.

In methods for liquefying nitrogen gas such as that disclosed in JP 2005-164150, the liquefying capability for liquefying the nitrogen gas depends on the temperature of the LNG supplied to the heat exchanger. That is, the lower the temperature of the LNG supplied to the heat exchanger, the greater the amount of liquefaction in the pressure reducing valve disposed downstream of the heat exchanger. Conversely, the amount of liquefaction decreases as the LNG temperature increases.

A decrease in the amount of liquefaction means that the amount of nitrogen gas generated when the nitrogen gas is decompressed by the pressure reducing valve increases. Since the pressure of the nitrogen gas generated by the decompression is low, the nitrogen gas must be compressed once again and

recycled, or released, and therefore nitrogen gas liquefaction is inefficient if the LNG temperature is high.

Meanwhile, concomitant with increases in the efficiency of natural gas turbines in recent years, the pressure of the natural gas being used has tended to increase. This has increased the need for LNG to be caused to evaporate at higher pressures.

In order to obtain a high natural gas pressure, generally the LNG stored in a tank is pressurised using a pump, after which the LNG is caused to evaporate. However, pressurising LNG using a pump raises the temperature of the LNG as a result of heat input from the pump. Therefore, pressurising LNG to a high pressure results in an increase in the LNG temperature. This results in the problem that the efficiency with which nitrogen gas is liquefied by utilizing the coldness of the LNG deteriorates.

In view of this situation, the objective of the present invention is to provide a gas liquefaction device and a gas liquefaction method employing said gas liquefaction device, capable of supplying high-pressure natural gas in a device which liquefies a feed gas with a high efficiency by utilizing the coldness of liquefied natural gas.

The gas liquefaction method according to the present invention includes

a first pressurising step of pressurising liquefied natural gas to a first pressure,

a second pressurising step of introducing into a main heat exchanger the liquefied natural gas pressurised in the first pressurising step, and then pressurising the pressure thereof to a second pressure higher than the first pressure,

a first natural gas discharging step of causing at least part of the liquefied natural gas pressurised in the second pressurising step to pass through the main heat exchanger, and discharging the same from the main heat exchanger as natural gas,

a feed gas compressing step of compressing a feed gas,

a feed gas cooling step of cooling the feed gas that has been compressed in the feed gas cooling step to a first temperature,

a gas-liquid separation step of decompressing and cooling the feed gas that has been cooled in the feed gas cooling step, and then subjecting the same to gas-liquid separation, and

a liquefied feed gas discharging step of discharging the liquefied feed gas obtained in the gas-liquid separation step, in a liquid state, wherein

the feed gas cooling step is a step of cooling the feed gas by means of heat exchange, in the main heat exchanger, between the liquefied natural gas pressurised in the first pressurising step and the liquefied natural gas pressurised in the second pressurising step, on the one hand, and the feed gas on the other hand.

According to this method, first the liquefied natural gas pressurised to the first pressure in the first pressurising step is introduced into the cold end of the main heat exchanger, and heat exchange is performed with the feed gas. The liquefied natural gas of which the temperature has been increased to a prescribed temperature by means of the heat exchange is discharged from an intermediate portion of the main heat exchanger, is pressurised to a second pressure in the second pressurising step, and the temperature is increased further. The liquefied natural gas of which the temperature has been increased is returned once again to the main heat exchanger, and releases coldness and vaporises as a result of heat exchange with the feed gas.

In this way, adopting a configuration in which the step of pressurising the liquefied natural gas comprises two stages makes it possible to suppress to a low pressure the pressure of the liquefied natural gas introduced into the cold end of the main heat exchanger, even if it is necessary to supply natural gas at a high pressure (for example, 80 barA or more). By reducing the pressure (first pressure) to which the pressure is increased in the first pressurising step, the increase in temperature of the liquefied natural gas in the first pressurising step can be reduced in comparison with a case in which the increased pressure is high. It is therefore possible to implement heat exchange between the liquefied natural gas at a low temperature and the feed gas, in the main heat exchanger, thereby increasing the feed gas liquefaction efficiency.

Exchanging heat between the low-temperature liquefied natural gas and the feed gas in the main heat exchanger to release the coldness of the liquefied natural gas to some extent, and then pressurising to the second pressure in the second pressurising step, makes it possible to obtain high-pressure gaseous natural gas by vaporising the liquefied natural gas.

In addition, with regard also to the liquefied natural gas of which the temperature has been increased in the second pressurising step, returning said

liquefied natural gas to the main heat exchanger, thereby further releasing the coldness thereof, allows the coldness of the liquefied natural gas to be utilized to cool the feed gas. Thus, since the coldness of the liquefied natural gas at a relatively low pressure (first pressure) and the coldness of the liquefied natural gas at a relatively high pressure (second pressure) are each utilized to cool the feed gas, this method can be said to be a feed gas liquefaction method having high thermal efficiency.

The gas liquefaction method according to the present invention can additionally include, in the gas-liquid separation step, a feed gas recycling step of causing the gaseous feed gas obtained by the gas-liquid separation to flow together with the feed gas to be subjected to the feed gas compressing step.

The decompressed and cooled feed gas which has been cooled by the main heat exchanger is in a gas-liquid mixed state, and the liquefied feed gas that has been liquefied is discharged as product.

Meanwhile, the cooled gaseous feed gas that has not been liquefied is caused to flow together with the feed gas, as recycled feed gas to be subjected once again to the compressing step and the subsequent feed gas cooling step.

Loss of feed gas can be avoided by recycling the part of the feed gas that has not been liquefied, in this way.

The gaseous feed gas may be introduced into the main heat exchanger after being discharged from the gas-liquid separator, and subjected to the feed gas compressing step after the coldness thereof has been released. Since the gaseous feed gas that is discharged from the gas-liquid separator is in a cooled state, the coldness thereof can be utilized to cool the feed gas in the feed gas cooling step, thereby enabling the feed gas liquefaction efficiency to be increased further.

The abovementioned gas liquefaction methods according to the present invention can additionally include a pre-cooling step of cooling the feed gas to a second temperature higher than the first temperature, wherein

the feed gas cooled in the pre-cooling step is compressed and is then subjected to the feed gas cooling step.

Since it is possible for the coldness of the liquefied natural gas to be utilized to pre-cool the feed gas prior to compression in the feed gas compressing step, the feed gas may be cooled to the second temperature in the pre-cooling step, by being passed through the main heat exchanger, and then subjected to the feed

gas compressing step. This is because it is possible to reduce the motive power used for compression by compressing the feed gas at a lower temperature.

The abovementioned gas liquefaction methods according to the present invention can additionally include an intermediate cooling step of cooling the feed gas compressed in the feed gas compressing step to a third temperature higher than the first temperature, wherein the feed gas cooled in the intermediate cooling step is further compressed and is then subjected to the feed gas cooling step.

The feed gas compressing step may be split into a plurality of compression stages, and the coldness of the liquefied natural gas may be utilized to cool the intermediate feed gas in the main heat exchanger. The gas temperature increases in the gas compressing step as a result of adiabatic compression, and the thermal efficiency deteriorates as the compression ratio increases. The thermal efficiency can thus be improved by applying intermediate cooling in the compressing step.

The gas liquefaction method according to the present invention can additionally include

a second natural gas discharging step of vaporising in an evaporator part of the liquefied natural gas that has been pressurised in the second pressurising step and that is not introduced into the main heat exchanger, and discharging the same from the evaporator as natural gas.

The entire volume of the liquefied natural gas pressurised in the second pressurising step can be introduced into the main heat exchanger, increased in temperature and vaporised, but a portion thereof may be introduced into an evaporator disposed independently from the main heat exchanger, without being introduced into the main heat exchanger. The liquefied natural gas introduced into the evaporator is vaporised in the evaporator, and is supplied as gaseous natural gas to a natural gas consumption site.

If the entire volume of the liquefied natural gas pressurised in the second pressurising step is introduced into the main heat exchanger, the amount of heat obtained by the liquefied natural gas by means of heat exchange with the feed gas may be insufficient to cause said entire volume to evaporate. This may lead to drawbacks arising from the fact that the entire volume of the natural gas discharged from the evaporator does not adopt a gaseous state, but adopts a gas-liquid mixed state, or that even if a gaseous state is achieved, the temperature may be too low.

Accordingly, the portion of the liquefied natural gas that cannot be caused to evaporate in the main heat exchanger is introduced into the evaporator, and is vaporised in the evaporator. The entire volume of liquefied natural gas pressurised in the second pressurising step can thus be caused to evaporate.

In the evaporator, coldness is released when the liquefied natural gas vaporises, but the thermal efficiency can be further improved by utilizing this coldness to cool the compressor used in the feed gas compressing step, for example.

The abovementioned gas liquefaction methods according to the present invention can additionally include a sub-cooling step for further cooling the liquefied feed gas in a liquid state that has been discharged in the liquefied feed gas discharging step.

The liquefied feed gas in a liquid state discharged in the liquefied feed gas discharging step can be stored without modification in a liquefied feed gas storage tank, but can also be stored after being cooled further by means of the sub-cooling step.

The temperature of the liquefied feed gas discharged in a liquid state in the liquefied feed gas discharging step is often a temperature relatively close to the liquefaction point of the feed gas. However, storing at this temperature may result in the generation of a large amount of boil-off gas during storage, reducing the storage efficiency in the liquid state. Accordingly, if the liquefied feed gas in a liquid state is cooled further through the sub-cooling step according to the present invention, the amount of boil-off gas can be reduced, and loss of feed gas due to vaporisation of the liquefied feed gas can be suppressed.

In the abovementioned invention, the feed gas should be a gas which is liquefied by being compressed and cooled by means of liquefied natural gas, and may, for example, be nitrogen gas, argon gas, or oxygen gas.

The gas liquefaction device according to the present invention is provided with

a first compressor for compressing a feed gas, a feed gas line which introduces the feed gas into the first compressor, and a compressed feed gas line which introduces the compressed feed gas into a main heat exchanger,

the main heat exchanger, which cools the feed gas that has been compressed by the first compressor,

a first pressure reducing valve which decompresses and cools the feed gas discharged from a cold end of the main heat exchanger,

a gas-liquid separator which subjects the feed gas that has been discharged from the first pressure reducing valve to gas-liquid separation,

a liquefied feed gas discharging line which discharges liquefied feed gas in a liquid state from the liquid phase of the gas-liquid separator,

a first pump which pressurises the liquefied natural gas to a first pressure,

a second pump which pressurises the liquefied natural gas to a second pressure higher than the first pressure,

a first liquefied natural gas line which introduces the liquefied natural gas that has been discharged from the first pump into the cold end of the main heat exchanger,

a second liquefied natural gas line which discharges from an intermediate portion of the main heat exchanger, at a temperature lower than the critical temperature of the liquefied natural gas, the liquefied natural gas introduced into the main heat exchanger through the first liquefied natural gas introducing line, and introduces the same into the second pump,

a third liquefied natural gas line which introduces at least part of the liquefied natural gas discharged from the second pump into an intermediate portion of the main heat exchanger, and

a first natural gas line which discharges from the warm end of the main heat exchanger the liquefied natural gas introduced into the main heat exchanger through the third liquefied natural gas line.

The feed gas is compressed by the first compressor, is then cooled by the main heat exchanger, and is decompressed and cooled by the first pressure reducing valve, thereby liquefying at least part thereof.

Heat exchange occurs between the feed gas and the liquefied natural gas in the main heat exchanger, and the feed gas is cooled by the coldness of the liquefied natural gas. The liquefied natural gas is pressurised to a prescribed pressurise (first pressure) by the first pump, is introduced into the cold end of the main heat exchanger, and releases coldness by means of heat exchange with the feed gas. The liquefied natural gas is then discharged from an intermediate portion of the main heat exchanger, is introduced into the second pump, and is pressurised to the second pressure by the second pump. The second pressure is higher than the first

pressure, and the temperature of the liquefied natural gas increases as a result of being pressurised from the first pressure to the second pressure. The liquefied natural gas having an increased temperature is once again introduced into the main heat exchanger, releases coldness further and is vaporised as a result of heat exchange with the feed gas, and is discharged from the warm end of the main heat exchanger.

As a result of being pressurised to the second pressure by the first pump, the temperature of the liquefied natural gas when introduced into the main heat exchanger (in other words, the temperature of the liquefied natural gas at the warm end of the main heat exchanger) is lower than if pressurised to the second pressure. Therefore, by not pressurising the liquefied natural gas to a pressure equal to or greater than the first pressure, sufficient coldness can be obtained in the main heat exchanger.

After exchanging heat with the liquefied natural gas at the first pressure, the liquefied natural gas is pressurised to the second pressure by the second pump. By being raised to the second pressure, the gaseous natural gas obtained after the liquefied natural gas has been vaporised can be supplied at high pressure. The coldness of the liquefied natural gas that has reached the second pressure is not sufficient to liquefy the feed gas, but is sufficient to cool the gaseous feed gas prior to liquefaction. The liquefied natural gas that has reached the second pressure is therefore introduced once again into the main heat exchanger, and the coldness thereof is utilized to cool the feed gas.

The feed gas that has been cooled by the main heat exchanger in this way is introduced from the cold end of the main heat exchanger into the first pressure reducing valve, and is decompressed and cooled. Here, the feed gas that is in a gas-liquid mixed state is separated into a gas phase and a liquid phase by the gas-liquid separator, and liquefied feed gas in a liquid state is discharged from the liquid phase part.

The gas liquefaction device according to the abovementioned invention can additionally include a recycled feed gas line which discharges the gaseous feed gas from the gas phase of the gas-liquid separator and causes the same to flow together upstream of the first compressor.

The gaseous feed gas separated to the gas phase of the gas-liquid separator can be released to the outside without modification, but may be caused to flow

together with the feed gas as recycled feed gas, prior to introduction into the first compressor. This is in order to prevent loss of feed gas by recycling once again to the liquefaction step the part of the feed gas that is not liquefied.

The recycled feed gas line may pass through the main heat exchanger.

The recycled feed gas has been cooled by way of the main heat exchanger and the first pressure reducing valve, and therefore by being passed through the main heat exchanger once again, the coldness thereof can be utilized to cool the feed gas. By adopting such a configuration, the coldness of the part of the feed gas that is not liquefied can also be efficiently utilized, thereby enabling the thermal efficiency of the gas liquefaction device as a whole to be improved.

In the gas liquefaction device according to the present invention, the feed gas line may pass through the main heat exchanger.

By cooling the feed gas prior to compression by the first compressor, the motive power used to compress the feed gas can be reduced.

The gas liquefaction device according to the abovementioned invention can additionally be provided with a second compressor which further compresses the compressed feed gas, a feed gas intermediate cooling line which introduces the compressed feed gas into the second compressor by way of the main heat exchanger, and a pressurised feed gas line which introduces the feed gas compressed by the second compressor into the main heat exchanger.

The feed gas compressed by the first compressor is introduced into the main heat exchanger. The feed gas is then cooled to a third temperature in the main heat exchanger and is discharged from an intermediate portion of the main heat exchanger. Here, the feed gas is compressed further by the second compressor and is once again introduced into the main heat exchanger. In this way, the motive power used to compress the feed gas can be reduced.

The gas liquefaction device according to the abovementioned invention can additionally be provided with an evaporator for vaporising part of the liquefied natural gas that has been pressurised by the second pump and that is not introduced into the main heat exchanger, and

a second natural gas line which discharges gaseous natural gas from the evaporator.

The entire volume of the liquefied natural gas pressurised by the second pump can be introduced into the main heat exchanger, but introducing into the

main heat exchanger coldness exceeding the amount of coldness required to cool the feed gas results in insufficient vaporisation of the liquefied natural gas. In such cases, the portion of the liquefied natural gas that is not vaporised by the main heat exchanger can be introduced into an evaporator disposed independently to the main heat exchanger, without being introduced into the main heat exchanger. Adopting such a configuration makes it possible to vaporise the entire volume of the liquefied natural gas pressurised by the second pump, and to discharge gaseous natural gas.

The gas liquefaction device according to the abovementioned invention can additionally be provided with a sub-cooler for cooling the liquefied feed gas discharged from the liquefied feed gas discharging line,

a second pressure reducing valve which decompresses and cools part of the liquefied feed gas discharged from the sub-cooler,

a first low-pressure recycled gas line which introduces feed gas discharged from the second pressure reducing valve into a cold end of the sub-cooler as low-pressure recycled feed gas,

a second low-pressure recycled gas line which introduces the low-pressure recycled feed gas discharged from a warm end of the sub-cooler into the cold end of the main heat exchanger, a third compressor which compresses the low-pressure recycled feed gas and causes the same to flow together upstream of the first compressor, and

a third low-pressure recycled gas line which causes the low-pressure recycled feed gas that has passed through the second low-pressure feed gas line and has been discharged from the warm end of the main heat exchanger to be compressed by the third compressor and to flow together upstream of the first compressor.

By means of the sub-cooler, the liquefied feed gas in a liquid state that has been separated to the liquid phase side of the gas-liquid separator can be cooled further. Lowering the temperature of the liquefied feed gas reduces vaporisation (in other words the generation of boil-off gas) of the feed gas during storage, thereby making it possible to reduce losses during storage of the liquefied feed gas.

A low-pressure feed gas line which introduces low-pressure feed gas having a pressure lower than the feed gas into the third compressor can additionally be provided.

If the pressure of the feed gas supplied from the outside is low, the feed gas can be compressed using the third compressor.

In the abovementioned invention, the feed gas should be a gas which is liquefied by being compressed and cooled by means of liquefied natural gas, and may, for example, be nitrogen gas, argon gas, or oxygen gas.

Brief description of the drawings

Figure 1 is a drawing illustrating a configuration example of embodiment 1 of a gas liquefaction device.

Figure 2 is a drawing illustrating a configuration example of alternative embodiment 1 of embodiment 1 of a gas liquefaction device.

Figure 3 is a drawing illustrating a configuration example of alternative embodiment 2 of embodiment 1 of a gas liquefaction device.

Figure 4 is a drawing illustrating a configuration example of embodiment 2 of a gas liquefaction device.

Figure 5 is a drawing illustrating a configuration example of embodiment 3 of a gas liquefaction device.

Figure 6 is a drawing illustrating a configuration example of embodiment 4 of a gas liquefaction device.

Figure 7 is a drawing illustrating a configuration example of embodiment 5 of a gas liquefaction device.

Figure 8 is a drawing illustrating a configuration example of embodiment 6 of a gas liquefaction device.

Figure 9 is a drawing illustrating a configuration example of embodiment 7 of a gas liquefaction device.

Figure 10 is a drawing illustrating a configuration example of embodiment 8 of a gas liquefaction device.

Modes for carrying out the invention

A number of embodiments of the present invention will now be described. The embodiments described hereinafter are used to describe examples of the present invention. The present invention is not limited in any way to the following embodiments, and includes various modifications implemented without changing the gist of the present invention. It should be noted that not all the configurations described below are necessarily essential configurations of the present invention.

Embodiment 1

A gas liquefaction device 100 in embodiment 1 and a gas liquefaction method employing the same will be described with reference to Figure 1.

The gas liquefaction device 100 according to the present invention is provided with: a first compressor 1 for compressing a feed gas; a feed gas line 29 which introduces the feed gas into the first compressor 1; a main heat exchanger 2 which cools the feed gas that has been compressed by the first compressor 1; a compressed feed gas line 30 which introduces the feed gas compressed by the first compressor 1 into the main heat exchanger 2; a first pressure reducing valve 3 which reduces the pressure of and cools the feed gas discharged from a cold end of the main heat exchanger 2; a gas-liquid separator 4 which subjects the feed gas that has been discharged from the first pressure reducing valve 3 to gas-liquid separation; a liquefied feed gas discharging line 21 which discharges liquefied feed gas in a liquid state from the liquid phase of the gas-liquid separator 4; a first pump 11 which pressurises the liquefied natural gas to a first pressure; a second pump 12 which pressurises the liquefied natural gas to a second pressure higher than the first pressure; a first liquefied natural gas line 22 which introduces the liquefied natural gas that has been discharged from the first pump 11 to the cold end of the main heat exchanger 2; a second liquefied natural gas line 23 which discharges from an intermediate portion of the main heat exchanger 2, at a temperature lower than the critical temperature of the liquefied natural gas, the liquefied natural gas introduced into the main heat exchanger 2 through the first liquefied natural gas introducing line 22, and introduces the same into the second pump 12; a third liquefied natural gas line 24 which introduces at least part of the liquefied natural gas discharged from the second pump 12 into an intermediate portion of the main heat exchanger 2; and a first natural gas line 25 which discharges from the warm

end of the main heat exchanger 2 the liquefied natural gas introduced into the main heat exchanger 2 through the third liquefied natural gas line 24.

In the present embodiment, nitrogen gas, serving as the feed gas to be liquefied, is introduced into the first compressor 11 of the gas liquefaction device 100, for example. The gas may be at a lower temperature than ambient temperature (25°C), but may, for example, be at a temperature at least equal to 0°C and at most equal to 65°C.

In a feed gas compressing step, the feed gas (having a flow rate of 1653 Nm^3, for example) is compressed to a prescribed pressure by the first compressor 1.

The first compressor 1 is a compressor for compressing, upstream of the main heat exchanger 2, the feed gas to be supplied to the main heat exchanger 2 and cooled. The feed gas is a gas which is liquefied after being cooled by the main heat exchanger 2, and may, for example, be nitrogen gas, argon gas, or oxygen gas, and may be a mixed gas thereof.

If the feed gas introduced into the first compressor 1 is nitrogen gas, the pressure of the nitrogen gas when introduced into the first compressor 1 is at least equal to 1 barA and at most equal to 12 barA, for example. The pressure of the feed gas introduced into the main heat exchanger 2 is at least equal to 40 barA and at most equal to 60 barA, for example.

In a feed gas cooling step, the feed gas compressed in the feed gas compressing step is cooled to a first temperature by the main heat exchanger 2.

The first temperature must be a temperature at which at least a portion of the feed gas liquefies downstream of the first pressure reducing valve 3, and is a temperature at least equal to -160°C and at most equal to -130°C, for example.

The feed gas is cooled by means of heat exchange with the liquefied natural gas, discussed hereinafter, inside the main heat exchanger 2.

It should be noted that the feed gas to be subjected to the feed gas compressing step may be cooled in advance.

In a gas-liquid separation step, the feed gas cooled in the feed gas cooling step is decompressed and cooled by the first pressure reducing valve 3, and is then subjected to gas-liquid separation by the gas-liquid separator 4 to obtain a gas phase and a liquid phase. By being passed through the pressure reducing valve 3, the feed gas reaches a temperature lower than that when discharged from the cold

end of the heat exchanger 2. As a result, the feed gas is introduced into the gas-liquid separator 4 at a temperature at least equal to -196°C and at most equal to -160°C.

A liquefied feed gas discharging step is a step in which the liquefied feed gas separated to the liquid phase of the gas-liquid separator 4 in the gas-liquid separation step is discharged from the liquefied feed gas discharging line 21 in a liquid state. The discharged feed gas is stored in a liquid state.

A first pressurising step is a step in which liquefied natural gas stored in a storage tank (having a flow rate of 3695 Nm^3/h, for example) is pressurised to a first pressure. The pressure of the liquefied natural gas in the storage tank is at least equal to atmospheric pressure, and is in a range at least equal to 1.013 barA and at most equal to 2 barA, for example. The first pressure is in a range at least equal to 7 barA and at most equal to 30 barA, for example.

The liquefied natural gas that has been pressurised to the first pressure is introduced into the main heat exchanger 2, and is then pressurised to a second pressure higher than the first pressure by the second pump 12.

The first pressure is set such that the saturation temperature at the pressure when the liquefied natural gas is introduced into the second pump 12 is higher than the temperature when introduced into the second pump, to prevent cavitation occurring in the second pump 12.

For example, if the temperature of the liquefied natural gas introduced into the second pump 12 is -120°C, the pressure of the liquefied natural gas introduced into the second pump 12 must be at least equal to 14 barA, which is the saturation pressure at -120°C, and the outlet pressure of the first pump 11 is set to allow a pressure equal to or greater than this pressure to be reached.

The liquefied natural gas discharged from the first pump 11 is introduced into the cold end of the main heat exchanger 2 by way of the first liquefied natural gas line 22, and is further introduced from an intermediate portion of the main heat exchanger 2 into the second pump 12 by way of the second liquefied natural gas line 23.

The temperature of the liquefied natural gas discharged to the second liquefied natural gas line 23 from the intermediate portion of the main heat exchanger 2 is a temperature lower than the saturation temperature of the liquefied natural gas.

The temperature of the liquefied natural gas stored in the storage tank rises as a result of heat input when pressurised by the first pump 11, but if this temperature rise is large, there is a risk that cooling and liquefaction of the feed gas by the heat exchanger 2 may be insufficient, resulting in impaired liquefaction efficiency. It is therefore preferable that pressurisation by the first pump 11 is suppressed to be as low as possible, within a pressure range in which the saturation temperature is not reached at the inlet of the second pump 12, so as to suppress an increase in the temperature of the liquefied natural gas from the first pump 11. The temperature of the liquefied natural gas introduced into the main heat exchanger 2 is at least equal to -162°C and at most equal to -140°C, for example.

A second pressurising step is a step of pressurising the liquefied natural gas to a second pressure higher than the first pressure by means of the second pump 12. The second pressure is determined in accordance with the natural gas pressure required when the vaporised natural gas is to be used, and if, for example, the gaseous natural gas needs to be supplied at a pressure at least equal to 50 barA and at most equal to 120 barA, the second pressure can be set to be at least equal to 51 barA and at most equal to 121 barA, in consideration of pressure losses and the like in the main heat exchanger 2.

A first natural gas discharging step is a step in which at least part of the liquefied natural gas pressurised by the second pump 12 is introduced into the main heat exchanger 2 by way of the third liquefied natural gas line 24, is vaporised, and is discharged in a gaseous state from the warm end of the main heat exchanger 2 by means of the first natural gas line 25. The discharged gaseous natural gas has a lower pressure than the second pressure (for example, at least equal to 50 barA and at most equal to 120 barA), and is used at a consumption site.

In a feed gas cooling step, the feed gas introduced into the main heat exchanger 2 from the warm end of the main heat exchanger 2 is subjected inside the main heat exchanger 2 to heat exchange with the liquefied natural gas that has passed through the third liquefied natural gas line 24. The feed gas cooled in this way is further cooled by being subjected to heat exchange with the liquefied natural gas that has passed through the first liquefied natural gas line 22, and is discharged from the cold end of the heat exchanger 2.

The feed gas is liquefied efficiently by being subjected to heat exchange with the sufficiently low temperature liquefied natural gas that has passed through

the first liquefied natural gas line 22. Furthermore, by being subsequently pressurised by means of the second pump 12, the gaseous natural gas can be supplied to a consumption site at a sufficient pressure.

In embodiment 1 discussed hereinabove, if natural gas at a high pressure (95 barA) is discharged with a flow rate of 3700 Nm^3/h, the liquefied natural gas is pressurised to a pressure of 20 barA by the first pump 11, and is further pressurised to a pressure of 95 barA by the second pump 12. The amount of liquefaction of the feed gas (nitrogen gas) in this case is 1000 Nm^3/h.

Meanwhile, if the pressurising step does not comprise two stages as in the present embodiment, and the liquefied natural gas is pressurised in one stage by means of one pressurising mechanism, the liquefied natural gas must be pressurised to 95 barA in one stage in order to discharge natural gas at an equivalent pressure. In a one-stage pressurising step, the temperature at which the liquefied natural gas is introduced into the main heat exchanger 2, which was -155°C in the present embodiment, rises to -147°C. The coldness released by the liquefied natural gas in the main heat exchanger 2 therefore decreases, and is insufficient to cool the feed gas. As a result, the amount of liquefaction of the feed gas becomes 810 Nm^3/h, which is less than in embodiment 1.

Thus, with the method according to the present embodiment in which the pressurising step comprises two stages, liquefaction can be effected with a higher efficiency than with a conventional feed gas liquefaction method in which the pressurising step comprises one stage.

Alternative embodiment 1

The gaseous feed gas (having a flow rate of 371 Nm^3/h, for example) separated to the gas phase side of the gas-liquid separator 4 in the gas-liquid separation step can be released to the outside of the system, as illustrated in Figure 1, but, as illustrated in Figure 2 as another embodiment, can also be passed through a recycled feed gas line 26, caused to flow together upstream of the first compressor 1, and subjected once again to the feed gas compressing step together with the feed gas. By providing such a feed gas recycling step, the feed gas in the gas phase part of the gas-liquid separator 4 is subjected once again to the feed gas compressing step as recycled feed gas, enabling a loss of gaseous feed gas to be suppressed.

Alternative embodiment 2

As illustrated in Figure 3 as yet another embodiment, the recycled feed gas (having a flow rate of 371 Nm^3/h, for example) discharged from the gas phase side of the gas-liquid separator 4 can be passed through the main heat exchanger 2 and then caused to flow together upstream of the first compressor 1. Since the gaseous recycled feed gas discharged from the gas phase side of the gas-liquid separator 4 has been cooled to a low temperature, for example at most equal to -180°C and at least equal to -160°C, the coldness therefore is released in the main heat exchanger 2 and is utilized to cool the feed gas, thereby enabling the liquefaction efficiency to be improved further.

The recycled feed gas that has passed through the main heat exchanger 2 may be discharged from the cold end of the main heat exchanger 2, or may be discharged from an intermediate portion of the main heat exchanger 2.

Embodiment 2

A gas liquefaction device 101 in embodiment 2 and a gas liquefaction method employing the same will be described with reference to Figure 4. Elements having the same reference codes as in the gas liquefaction device in the embodiment described hereinabove have the same function, and descriptions thereof are therefore omitted.

In the gas liquefaction device 101 in embodiment 2, pre-cooling of the feed gas is carried out in a pre-cooling step before the feed gas is introduced into the first compressor.

In the feed gas pre-cooling step, the feed gas is introduced into the main heat exchanger 2 from the warm end of the main heat exchanger 2, and is cooled. The temperature of the feed gas when introduced into the warm end of the main heat exchanger 2 is at least equal to 0°C and at most equal to 65°C, for example, and the feed gas is cooled inside the main heat exchanger 2 to at least -110°C and at most -50°C, for example, and is then discharged from an intermediate portion of the main heat exchanger 2. Here, the intermediate portion of the main heat exchanger 2 from which the pre-cooled feed gas is discharged is closer to the warm end of the main heat exchanger 2 than the point at which the liquefied natural gas is re-introduced into the main heat exchanger 2 by the second pump 12.

The feed gas discharged from the intermediate portion of the main heat exchanger 2 is introduced into the first compressor 1 and is compressed.

Embodiment 3

A gas liquefaction device 102 in embodiment 3 and a gas liquefaction method employing the same will be described with reference to Figure 5. Elements having the same reference codes as in the gas liquefaction device in the embodiments described hereinabove have the same function, and descriptions thereof are therefore omitted.

In the gas liquefaction device 102 in embodiment 3, intermediate cooling of the feed gas is carried out in an intermediate cooling step after the feed gas compressing step has been carried out.

The feed gas compressed by the first compressor 1 in the feed gas compressing step is introduced in the subsequent intermediate cooling step into the main heat exchanger 2 from the warm end of the main heat exchanger 2, and is cooled. The temperature of the feed gas when introduced into the warm end of the main heat exchanger 2 is at least equal to 0°C and at most equal to 65°C, for example, and the feed gas is subjected to intermediate cooling inside the main heat exchanger 2 to at least -110°C and at most -50°C, for example, and is then discharged from an intermediate portion of the main heat exchanger 2. Here, the intermediate portion of the main heat exchanger 2 from which the intermediate-cooled feed gas is discharged is closer to the warm end of the main heat exchanger 2 than the point at which the liquefied natural gas is re-introduced into the main heat exchanger 2 by the second pump 12.

The feed gas discharged from the intermediate portion of the main heat exchanger 2 is introduced into a second compressor 6 and is compressed. By this means, the pressure of the feed gas discharged from the first compressor 1 at a pressure at least equal to 10 barA and at most equal to 30 barA, for example, is discharged from the second compressor 6 at a pressure at least equal to 40 barA and at most equal to 60 barA.

The feed gas discharged from the second compressor 6 passes through a pressurised feed gas line 32, is introduced once again into the main heat exchanger 2 from the warm end of the main heat exchanger 2, and is subjected to the subsequent feed gas cooling step.

Embodiment 4

A gas liquefaction device 103 in embodiment 4 and a gas liquefaction method employing the same will be described with reference to Figure 6. Elements having the same reference codes as in the gas liquefaction device in embodiment 1 described hereinabove have the same function, and descriptions thereof are therefore omitted.

The gas liquefaction device 103 in embodiment 4 includes a second natural gas discharging step of introducing into an evaporator 5 for vaporisation part of the liquefied natural gas (having a flow rate of 3277 Nm^3/h, for example) that has been pressurised by the second pump 12 in the second pressurising step (at a flow rate of 3695 Nm^3/h, for example) and that is not introduced into the main heat exchanger 2, and discharging the same in a gaseous state from the evaporator 5 through a second natural gas line 27.

A flow ratio between the liquefied natural gas that passes through the third liquefied natural gas line 24 from the second pump 12 to the main heat exchanger 2 and the liquefied natural gas introduced into the evaporator 5 can be determined in accordance with the amount of heat in the feed gas (in other words, the flow rate, pressure and temperature of the feed gas), and may, for example, be within a range of between 2:8 and 9:1. If the amount of heat in the feed gas is large, the flow rate of the liquefied natural gas introduced into the heat exchanger 2 can be increased, and if the amount of heat in the feed gas is small, the flow rate of the liquefied natural gas introduced into the evaporator 5 can be increased. By performing such an adjustment, the entire volume of both the natural gas discharged from the main heat exchanger by way of the first natural gas line 25 and the natural gas discharged from the evaporator 5 by way of the second natural gas line 27 can be discharged in a vaporised state.

Embodiment 5

A gas liquefaction device 104 in embodiment 5 and a gas liquefaction method employing the same will be described with reference to Figure 7. Elements having the same reference codes as in the gas liquefaction device in the embodiments described hereinabove have the same function, and descriptions thereof are therefore omitted.

In the gas liquefaction device 104 in embodiment 5, the liquefied feed gas discharged from the liquefied feed gas discharging line 21 in the liquefied feed gas discharging step is cooled further in a sub-cooling step.

In the sub-cooling step, the liquefied feed gas (having a flow rate of 1281 Nm^3/h, for example) cooled to at least -180°C and at most -160°C by the gas-liquid separator 4 and separated to the liquid phase side is introduced into a sub-cooler 8 by way of the liquefied feed gas discharging line 21. Here, the liquefied feed gas is cooled to a temperature at least equal to -196°C and at most equal to -175°C, for example. The liquefied feed gas (having a flow rate of 1281 Nm^3/h, for example) cooled inside the sub-cooler 8 is discharged from the sub-cooler 8 by way of a supercooled liquefied feed gas line 41. A portion (having a flow rate of 1000 Nm^3/h, for example) of the discharged liquefied feed gas may be delivered in a liquid state to a consumption site or may be stored in a storage tank.

A portion (having a flow rate of 281 Nm^3/h) of the liquefied feed gas discharged from the sub-cooler 8 by way of the supercooled liquefied feed gas line 41 is passed through a second pressure reducing valve 9 provided in a first low-pressure recycled feed gas line 42 which branches from the line 41, and is thereby decompressed and cooled. Here, the low-pressure recycled feed gas in a gas-liquid mixed state that has been decompressed and cooled is introduced into the sub-cooler 8 from the cold end side of the sub-cooler 8, at a temperature at least equal to -196°C and at most equal to -176°C, for example. By carrying out heat exchange between the low-pressure recycled feed gas introduced into the sub-cooler 8 from the line 42 and the liquefied feed gas introduced into the sub-cooler 8 by way of the liquefied feed gas discharging line 21, coldness is released inside the sub-cooler 8.

The low-pressure recycled feed gas after the coldness has been released is discharged to a second low-pressure recycled feed gas line 33 from the warm end side of the sub-cooler 8, at a temperature at least equal to -174°C and at most equal to -155°C, for example, and is then introduced into the main heat exchanger 2 from the cold end side of the main heat exchanger 2. Coldness is released further by means of heat exchange with the feed gas inside the main heat exchanger 2, and the low-pressure recycled feed gas is discharged from the warm end side of the main heat exchanger 2 to a third low-pressure recycled feed gas line 34, at a temperature at least equal to 0°C and at most equal to 65°C. The discharged low-

pressure recycled feed gas is compressed by a third compressor 7 and is then sent to the upstream side of the first compressor 1. Upstream of the first compressor 1, the starting material feed gas, the low-pressure recycled feed gas that has passed through the third low-pressure recycled feed gas line 34, and the recycled feed gas that has passed through the recycled feed gas line 26 flow together upstream of the first compressor 1 and are mixed, and are then subjected to the feed gas compressing step.

The third compressor 7 can be a low-temperature compressor capable of compressing low-temperature liquefied gas.

As an alternative embodiment, the feed gas can also flow together upstream of the third compressor 7, as illustrated in Figure 8. The position at which the feed gas is introduced can be selected in accordance with the pressure of the feed gas.

If the pressure of the supplied feed gas is higher than the pressure of the gas phase part of the gas-liquid separator 4, the feed gas is preferably introduced upstream of the first compressor 1 (see Figure 6). Conversely, if the pressure of the supplied feed gas is lower than the pressure of the gas phase part of the gas-liquid separator 4, the feed gas is preferably introduced upstream of the third compressor 7 (see Figure 7).

It should be noted that the temperature of the feed gas is increased by being compressed by the compressor, and therefore an after-cooler for cooling the same may be provided downstream of the compressor.

In a gas liquefaction device 105 in embodiment 6 illustrated in Figure 9, the recycled feed gas discharged from the gas phase part of the gas-liquid separator 4 and/or the low-pressure recycled feed gas discharged from the sub-cooler 8 is discharged from an intermediate portion of the main heat exchanger 2. The recycled feed gas is compressed by the first compressor 1 together with the feed gas cooled by the main heat exchanger 2. The low-pressure recycled gas is compressed by the third compressor 7.

The gas discharged from the third compressor 7 may be cooled by the main heat exchanger 2 and then introduced into the first compressor 1.

The feed gas may be introduced into the first compressor 1 after flowing together with the low-pressure recycled feed gas discharged from the third compressor 7.

Figure 10 illustrates an alternative embodiment. Here, the starting material feed gas may be introduced into the third compressor 7 after having been cooled by the main heat exchanger 2. The feed gas and the recycled feed gas may be introduced into the first compressor 1 after being mixed downstream of the third compressor 7.

After-coolers may be installed at the outlets of the first compressor 1 and the second compressor 7. The temperature of the recycled feed gas discharged from the intermediate portion of the main heat exchanger 2 or of the low-pressure recycled feed gas is at least equal to -120°C and at most equal to -50°C, for example. This configuration enables low-temperature gas to be compressed, thereby making it possible to reduce the motive power of the compressor.

Explanation of the reference codes

1. First compressor
2. Main heat exchanger
3. First pressure reducing valve
4. Gas-liquid separator
5. Evaporator
6. Second compressor
7. Third compressor
8. Sub-cooler
9. Second pressure reducing valve
11. First pump
12. Second pump
21. Liquefied feed gas discharging line
22. First liquefied natural gas line
23. Second liquefied natural gas line
24. Third liquefied natural gas line
25. First natural gas line
26. Recycled feed gas line
27. Second natural gas line
28. Feed gas pre-cooling line
29. Feed gas line
30. Compressed feed gas line
31. Feed gas intermediate cooling line
32. Pressurised feed gas line
33. Second low-pressure recycled feed gas line
34. Third low-pressure recycled feed gas line
41. Supercooled liquefied feed gas line
42. First low-pressure recycled feed gas line
100. Gas liquefaction device

CLAIMS

1. Gas liquefaction method including

a first pressurising step of pressurising liquefied natural gas to a first pressure,

a second pressurising step of introducing into a main heat exchanger the liquefied natural gas pressurised in the first pressurising step, and then pressurising the pressure thereof to a second pressure higher than the first pressure,

a first natural gas discharging step of causing at least part of the liquefied natural gas pressurised in the second pressurising step to pass through the main heat exchanger, and discharging the same from the main heat exchanger as natural gas,

a feed gas compressing step of compressing a feed gas,

a feed gas cooling step of cooling the feed gas that has been compressed in the feed gas cooling step to a first temperature,

a gas-liquid separation step of decompressing and cooling the feed gas that has been cooled in the feed gas cooling step, and then subjecting the same to gas-liquid separation, and

a liquefied feed gas discharging step of discharging the liquefied feed gas obtained in the gas-liquid separation step, in a liquid state, wherein

the feed gas cooling step is a step of cooling the feed gas by means of heat exchange, in the main heat exchanger, between the liquefied natural gas pressurised in the first pressurising step and the liquefied natural gas pressurised in the second pressurising step, on the one hand, and the feed gas on the other hand.

2. Gas liquefaction method according to Claim 1, wherein the gas-liquid separation step additionally includes a feed gas recycling step of causing the gaseous feed gas obtained by the gas-liquid separation to flow together with the feed gas to be subjected to the feed gas compressing step.

3. Gas liquefaction method according to Claim 1 or Claim 2, additionally including a pre-cooling step of cooling the feed gas to a second temperature higher than the first temperature, wherein

the feed gas cooled in the pre-cooling step is compressed and is then subjected to the feed gas cooling step.

4. Gas liquefaction method according to any one of Claim 1 to Claim 3, additionally including an intermediate cooling step of cooling the feed gas compressed in the feed gas compressing step to a third temperature higher than the first temperature, wherein the feed gas cooled in the intermediate cooling step is further compressed and is then subjected to the feed gas cooling step.

5. Gas liquefaction method according to any one of Claim 1 to Claim 4, additionally including a second natural gas discharging step of vaporising in an evaporator part of the liquefied natural gas that has been pressurised in the second pressurising step and that is not introduced into the main heat exchanger, and discharging the same from the evaporator as natural gas.

6. Gas liquefaction method according to any one of Claim 1 to Claim 5, additionally including a sub-cooling step for further cooling the liquefied feed gas in a liquid state that has been discharged in the liquefied feed gas discharging step.

7. Gas liquefaction method according to any one of Claim 1 to Claim 6, wherein the feed gas is nitrogen gas, argon gas, oxygen gas, or a mixed gas containing any two or more of said gases.

8. Gas liquefaction device provided with

a first compressor for compressing a feed gas, a feed gas line which introduces the feed gas into the first compressor, and a compressed feed gas line which introduces the compressed feed gas into a main heat exchanger,

the main heat exchanger, which cools the feed gas that has been compressed by the first compressor,

a first pressure reducing valve which decompresses and cools the feed gas discharged from a cold end of the main heat exchanger,

a gas-liquid separator which subjects the feed gas that has been discharged from the first pressure reducing valve to gas-liquid separation,

a liquefied feed gas discharging line which discharges liquefied feed gas in a liquid state from the liquid phase of the gas-liquid separator,

a first pump which pressurises the liquefied natural gas to a first pressure,

a second pump which pressurises the liquefied natural gas to a second pressure higher than the first pressure,

a first liquefied natural gas line which introduces the liquefied natural gas that has been discharged from the first pump into the cold end of the main heat exchanger,

a second liquefied natural gas line which discharges from an intermediate portion of the main heat exchanger, at a temperature lower than the critical temperature of the liquefied natural gas, the liquefied natural gas introduced into the main heat exchanger through the first liquefied natural gas introducing line, and introduces the same into the second pump,

a third liquefied natural gas line which introduces at least part of the liquefied natural gas discharged from the second pump into an intermediate portion of the main heat exchanger, and

a first natural gas line which discharges from the warm end of the main heat exchanger the liquefied natural gas introduced into the main heat exchanger through the third liquefied natural gas line.

9. Gas liquefaction device according to Claim 8, additionally including a recycled feed gas line which discharges the gaseous feed gas from the gas phase of the gas-liquid separator and causes the same to flow together upstream of the first compressor.

10. Gas liquefaction device according to Claim 9, characterized in that the recycled feed gas line passes through the main heat exchanger.

11. Gas liquefaction device according to any one of Claim 8 to Claim 10, characterized in that the feed gas line passes through the main heat exchanger.

12. Gas liquefaction device according to any one of Claim 8 to Claim 11, additionally comprising a second compressor which further compresses the feed gas compressed by the first compressor, a feed gas intermediate cooling line which introduces the compressed feed gas into the second compressor by way of the main

heat exchanger, and a pressurised feed gas line which introduces the feed gas compressed by the second compressor into the main heat exchanger.

13. Gas liquefaction device according to any one of Claims 8 to 12, additionally provided with an evaporator for vaporising part of the liquefied natural gas that has been pressurised by the second pump and that is not introduced into the main heat exchanger, and

a second natural gas line which discharges gaseous natural gas from the evaporator.

14. Gas liquefaction device according to any one of Claims 8 to 13, additionally provided with a sub-cooler for cooling the liquefied feed gas discharged from the liquefied feed gas discharging line,

a supercooled liquefied feed gas line which discharges liquefied feed gas in a supercooled state from the sub-cooler,

a second pressure reducing valve which decompresses and cools part of the supercooled liquefied feed gas discharged from the supercooled liquefied feed gas line,

a first low-pressure recycled feed gas line which introduces low-pressure recycled feed gas discharged from the second pressure reducing valve to a cold end of the sub-cooler,

a second low-pressure recycled feed gas line which introduces the low-pressure recycled feed gas discharged from a warm end of the sub-cooler into the cold end of the main heat exchanger, a third compressor which compresses the low-pressure recycled feed gas and causes the same to flow together upstream of the first compressor, and a third low-pressure recycled feed gas line which introduces the low-pressure recycled feed gas into the third compressor by way of the main heat exchanger.

15. Gas liquefaction device according to Claim 14, additionally provided with a low-pressure feed gas line which introduces low-pressure feed gas having a pressure lower than the feed gas into the third compressor.