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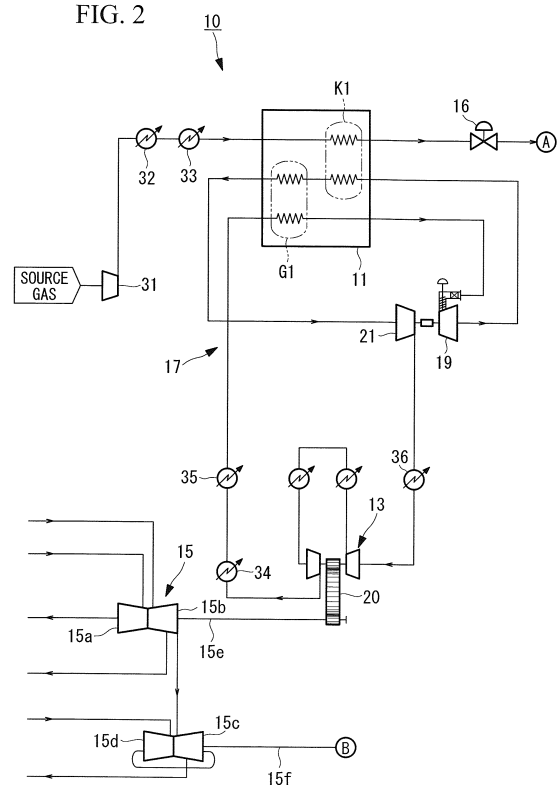
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(54) **LIQUEFACTION METHOD, LIQUEFACTION DEVICE, AND FLOATING LIQUEFIED GAS PRODUCTION EQUIPMENT COMPRISING SAME**

(57) Provided is a liquefaction method, a liquefying apparatus, and a floating liquefied-gas production facility equipped with the same, with which it is possible to suppress a decrease in liquefaction efficiency when gas to be liquefied is liquefied, to ensure safety, and to make the facility compact. Gas to be liquefied that has been subjected to heat exchange with a high-pressure heating medium composed of a single component is reduced in pressure, after which the gas to be liquefied that has been reduced in pressure is made to exchange heat with a low-temperature-side heating medium that is lower in temperature than and of the same type as the high-pressure heating medium.

FIG. 2



Description

{Technical Field}

[0001] The present invention relates to a liquefaction method, a liquefying apparatus, and a floating liquefied-gas production facility equipped with the same, and more specifically, it relates to liquefaction of natural gas.

{Background Art}

[0002] Typically, liquefaction facilities on land liquefy gas to be liquefied by using cascade refrigeration cycles or refrigeration cycles that employ a mixed refrigerant composed of several kinds of refrigerants (for example, PTL 1). In recent years, installing such liquefaction facilities on offshore floating platforms has been investigated. When a liquefaction facility similar to one used on land is to be installed on an offshore floating platform, it is necessary to make the facility suitable for use on a ship, taking into consideration anti-shaking performance, installation space, ease of liquefaction, and safety. Therefore, even a nitrogen expansion cycle using nitrogen refrigerant, which is used to reliquefy boil-off gas in an LNG ship but does not have good liquefaction efficiency when used in a liquefaction facility, has a possibility of being used.

{Citation List}

{Patent Literature}

[0003]

{PTL 1} Japanese Translation of PCT International Application, Publication No. 2006-504928

{PTL 2} Japanese Translation of PCT International Application, Publication No. 2006-503252

{Summary of Invention}

{Technical Problem}

[0004] Heat exchange between natural gas and nitrogen in a nitrogen refrigeration cycle will be described using FIG. 5. In FIG. 5, the vertical axis shows temperature (°C), and the horizontal axis shows heat load (kW). Furthermore, the solid line in FIG. 5 shows natural gas pressurized to 4 MPa, and the dashed line shows natural gas pressurized to 15 MPa. Moreover, the one-dot chain line in FIG. 5 shows nitrogen that exchanges heat with the natural gas pressurized to 4 MPa, and the two-dot chain line shows nitrogen that exchanges heat with the natural gas pressurized to 15 MPa.

[0005] As shown in FIG. 5, when the natural gas (solid line) is pressurized to 4 MPa, in the process in which the temperature changes, the temperature change of the natural gas is small relative to the heat load, forming a step

shape. This step shape appears because the temperature of nitrogen, which serves as refrigerant, is constant while transforming between a liquid phase and a gas phase in the heat exchange process. Therefore, when the conditions of nitrogen (one-dot chain line) are set in accordance with a pinch point at which the temperature difference between the natural gas pressurized to 4 MPa and the nitrogen is smallest, the temperature difference between the natural gas and the nitrogen increases in the heat exchange process other than the pinch point, typically resulting in a low liquefaction efficiency compared with the case where the temperature difference is small.

[0006] A nitrogen compressor that compresses and circulates nitrogen, which serves as a heating medium, requires great motive power and thus is usually driven by a gas turbine, as in the invention disclosed in PTL 2. It is assumed that a portion of the source gas to be liquefied is consumed as fuel by the gas turbine. Off-gas produced in the liquefaction process is less likely to be used because it is at too low pressure for use as gas turbine fuel and requires recompression. To maximize the amount of liquefied gas produced as a product, efficient conversion of process off-gas into fuel has been a problem.

[0007] Furthermore, the off-gas produced in the liquefaction process is substantially at atmospheric pressure and contains a large amount of nitrogen component. Thus, there has been a problem in that it is difficult to use the off-gas as fuel for the gas turbine that drives the nitrogen compressor.

[0008] Moreover, when the nitrogen compressor is driven by a hybrid of a gas turbine and a steam turbine or by a hybrid of a steam turbine and an electric motor, as in the invention disclosed in PTL 2, there have been problems that must be overcome to make it usable on an offshore floating platform, such as the difficulty in maintenance on a ship, the need for spare parts, and ensuring redundancy by motorization.

[0009] On the other hand, as shown by the dashed line in FIG. 5, when the natural gas is pressurized to 15 MPa, the step shape appearing with the natural gas pressurized to 4 MPa, which is shown by the solid line, disappears and a substantially straight-line shape appears. Therefore, it is possible to make the high-pressure natural gas pressurized to 15 MPa and the nitrogen (two-dot chain line) exchange heat with a reduced temperature difference therebetween over the entire range, and thus, it is possible to enable efficient liquefaction. However, there has been a problem in that, because a shell-and-tube type heat exchanger needs to be used to make the high-pressure natural gas and the nitrogen exchange heat, the size of the heat exchanger is large, and thus, it is impossible to reduce the installation space for the liquefying apparatus.

[0010] The present invention has been made in view of these circumstances, and it provides a liquefaction method, a liquefying apparatus, and a floating liquefied-

gas production facility equipped with the same, with which safety is ensured, and the facility can be made compact, while suppressing decrease in liquefaction efficiency.

{Solution to Problem}

[0011] To overcome the above-described problems, a liquefaction method, a liquefying apparatus, and a floating liquefied-gas production facility equipped with the same of the present invention employ the following solutions.

A first aspect of the present invention is a liquefaction method wherein gas to be liquefied that has been subjected to heat exchange with a high-pressure heating medium composed of a single component is reduced in pressure to a predetermined pressure, after which the gas to be liquefied that has been reduced in pressure is made to exchange heat with a low-temperature-side heating medium that is lower in temperature than and of the same type as the high-pressure heating medium.

[0012] The gas to be liquefied is liquefied by making the gas exchange heat with the heating medium. For the sake of the liquefaction efficiency of the gas to be liquefied, it is desirable that the temperature difference between the gas to be liquefied and the heating medium be uniformly small through the entire heat exchange process. However, when the gas to be liquefied is at high pressure, although the temperature difference between the gas and the heating medium is substantially uniformly small through the entire heat exchange process, the size of the heat exchanger that performs heat exchange between the gas and the heating medium increases. Furthermore, when the gas to be liquefied is at low pressure, the gas to be liquefied forms a step shape in the heat exchange process. Therefore, if the pressure of the heating medium is set in accordance with the position where the temperature difference between the gas to be liquefied and the heating medium is smallest (pinch point), the temperature difference between the gas to be liquefied and the heating medium increases in the process other than the pinch point, resulting in a decreased in heat exchange efficiency.

[0013] Hence, in order to reduce the temperature difference between the gas to be liquefied and the heating medium, a cascade system is used, which performs heat exchange in a plurality of heat exchangers using a mixed heating medium composed of hydrocarbon, nitrogen, etc., or a plurality of heating media each composed of a single component. The cascade system has a problem in that the number of devices, such as heat exchangers, increases. Furthermore, when a mixed heating medium is used, because it is composed of a plurality of components, a plurality of heating media are used according to the properties of the gas to be liquefied. However, there is a safety problem because some of these heating media are flammable.

[0014] Hence, in the present invention, the gas to be

liquefied is made to exchange heat with a high-temperature-side heating medium composed of a single component and is then reduced in pressure to a predetermined pressure. In addition, the gas to be liquefied that has been reduced in pressure is made to exchange heat with the low-temperature-side heating medium which is of the same type as the high-temperature-side heating medium and is lower in temperature than the high-temperature-side heating medium. With this configuration, it is possible to reduce the pressure of the gas to be liquefied that has exchanged heat with the high-temperature-side heating medium so as to approximate the temperature change of the low-temperature-side heating medium and then to make the gas exchange heat with the low-temperature-side heating medium. Thus, the temperature differences between the gas to be liquefied and the high-temperature-side heating medium and between the gas to be liquefied and the low-temperature-side heating medium can be maintained substantially constant. Accordingly, it is possible to efficiently liquefy the gas to be liquefied using the heating medium composed of a single component.

Note that the predetermined pressure is a pressure of the gas to be liquefied that exchanges heat with the heating medium corresponding to the critical point.

Furthermore, the gas to be liquefied is the source gas before being liquefied, and examples thereof include natural gas (LNG) and liquefied petroleum gas (LPG).

[0015] A second aspect of the present invention is a liquefying apparatus including a high-temperature-side-heating-medium heat exchanger that performs heat exchange between gas to be liquefied and a high-temperature-side heating medium; a reducing valve that reduces the pressure of the gas to be liquefied discharged from the high-temperature-side-heating-medium heat exchanger; and a low-temperature-side-heating-medium heat exchanger that performs heat exchange between the gas to be liquefied which has passed through the reducing valve and a low-temperature-side heating medium. The high-temperature-side heating medium and the low-temperature-side heating medium are made of a single component and are of the same type. The reducing valve reduces the pressure of the gas to be liquefied that will be guided to the low-temperature-side-heating-medium heat exchanger to a predetermined pressure.

[0016] The high-temperature-side heating medium composed of a single component is guided to the high-temperature-side-heating-medium heat exchanger, the low-temperature-side heating medium of the same type as the high-temperature-side heating medium is guided to the low-temperature-side-heating-medium heat exchanger, and the reducing valve that reduces the pressure of the gas to be liquefied to a predetermined pressure is provided between the high-temperature-side-heating-medium heat exchanger and the low-temperature-side-heating-medium heat exchanger. With this configuration, it is possible to make the gas to be liquefied

that has passed through the high-temperature-side-heating-medium heat exchanger approximate the temperature change of the low-temperature-side heating medium by the reducing valve and to guide the gas to the low-temperature-side-heating-medium heat exchanger. Thus, the temperature differences between the gas to be liquefied and the high-temperature-side heating medium and between the gas to be liquefied and the low-temperature-side heating medium can be maintained substantially constant. Accordingly, it is possible to efficiently liquefy the gas to be liquefied using the heating medium composed of a single component.

[0017] A third aspect of the present invention is a liquefying apparatus including a cross compound turbine having a high-pressure turbine that is driven by steam guided thereto, a high-pressure-turbine-side shaft that is connected to the high-pressure turbine, a low-pressure turbine that is driven by the steam discharged from the high-pressure turbine and guided thereto, and a low-pressure-turbine-side shaft that is connected to the low-pressure turbine; a high-temperature-side-heating-medium compressor that compresses a high-temperature-side heating medium guided to the high-temperature-side-heating-medium heat exchanger; a low-temperature-side-heating-medium compressor that compresses a low-temperature-side heating medium guided to the low-temperature-side-heating-medium heat exchanger; and a steam generating means that generates steam to be guided to the high-pressure turbine. The high-temperature-side-heating-medium compressor is connected to the high-pressure-turbine-side shaft. The low-temperature-side-heating-medium compressor is connected to the low-pressure-turbine-side shaft.

[0018] The high-temperature-side-heating-medium compressor is connected to the high-pressure-turbine-side shaft, and the low-temperature-side-heating-medium compressor is connected to the low-pressure-turbine-side shaft. Because the high-pressure-turbine-side shaft and the low-pressure-turbine-side shaft constituting the cross compound turbine are separated from each other, it is possible to independently control the high-temperature-side-heating-medium compressor and the low-temperature-side-heating-medium compressor by respectively controlling the high-pressure turbine connected to the high-pressure-turbine-side shaft and the low-pressure turbine connected to the low-pressure-turbine-side shaft. Accordingly, it is possible to independently compress the high-temperature-side heating medium and the low-temperature-side heating medium and to independently control the refrigeration load of the high-temperature-side heating medium and that of the low-temperature-side heating medium.

[0019] In any one of the above-described liquefying apparatuses of the present invention, the high-temperature-side-heating-medium heat exchanger may be of a plate type.

[0020] With this configuration, the high-temperature-side-heating-medium heat exchanger that performs heat

exchange between the gas to be liquefied and the high-temperature-side heating medium is of a plate type. Thus, it is possible to reduce the size of the high-temperature-side-heating-medium heat exchanger. Accordingly, it is possible to make the liquefying apparatus compact.

[0021] In any one of the above-described liquefying apparatuses of the present invention, the steam generating means may be configured to generate steam by using off-gas in the liquefied gas as fuel.

[0022] With this configuration, the steam generating means that generates steam by burning the off-gas in the liquefied gas as fuel is used. Thus, it is possible to generate steam used to drive the cross compound turbine using the off-gas produced in the liquefying apparatus substantially at an atmospheric pressure. Accordingly, it is possible to effectively utilize the off-gas produced by the liquefying apparatus.

[0023] A fourth aspect of the present invention is a floating liquefied-gas production facility including any one of the above-described liquefying apparatuses.

[0024] The liquefying apparatus including the cross compound turbine driven by steam is used in the floating liquefied-gas production facility. Thus, it is possible to use a steam turbine used in an existing marine main engine as the cross compound turbine. Accordingly, it is possible to effectively utilize an existing apparatus, without needing to develop a new cross compound turbine for driving the high-temperature-side-heating-medium compressor and the low-temperature-side-heating-medium compressor.

[0025] In the above-described floating liquefied-gas production facility of the present invention, the high-temperature-side heating medium and the low-temperature-side heating medium may employ nitrogen.

[0026] The liquefying apparatus that includes the high-temperature-side-heating-medium compressor, the low-temperature-side-heating-medium compressor, the high-temperature-side-heating-medium heat exchanger, and the low-temperature-side-heating-medium heat exchanger, which use non-flammable nitrogen as the heating medium, is used in the floating liquefied-gas production facility. Furthermore, the steam turbine is used to drive the high-temperature-side-heating-medium compressor and the low-temperature-side-heating-medium compressor. With this configuration, it is possible to eliminate the risk of explosion caused by flammable gas leaking from the heating medium or the like. Thus, it is possible to dispose apparatuses, such as the high-temperature-side-heating-medium compressor, the low-temperature-side-heating-medium compressor, and the steam turbine, below deck. Accordingly, it is possible to reduce the space for disposing the liquefying apparatus above deck.

{Advantageous Effects of Invention}

[0027] According to the present invention, the gas to

be liquefied is made to exchange heat with the high-temperature-side heating medium composed of a single component and is then reduced in pressure to a predetermined pressure. In addition, the gas to be liquefied that has been reduced in pressure is made to exchange heat with the low-temperature-side heating medium which is of the same type as the high-temperature-side heating medium and is lower in temperature than the high-temperature-side heating medium. With this configuration, it is possible to reduce the pressure of the gas to be liquefied that has exchanged heat with the high-temperature-side heating medium so as to approximate the temperature change of the low-temperature-side heating medium and then to make the gas exchange heat with the low-temperature-side heating medium. Thus, the temperature differences between the gas to be liquefied and the high-temperature-side heating medium and between the gas to be liquefied and the low-temperature-side heating medium can be maintained substantially constant. Accordingly, it is possible to efficiently liquefy the gas to be liquefied using the heating medium composed of a single component.

{Brief Description of Drawings}

[0028]

{FIG. 1} FIG. 1 is a schematic diagram showing the configuration of a floating liquefied-gas production facility including a liquefying apparatus according to an embodiment of the present invention.

{FIG. 2} FIG. 2 is an enlarged diagram showing the configuration on the right side of the liquefying apparatus shown in FIG. 1.

{FIG. 3} FIG. 3 is an enlarged diagram showing the configuration on the left side of the liquefying apparatus shown in FIG. 1.

{FIG. 4} FIG. 4 is a T-H graph showing the relationships for natural gas and nitrogen in the liquefying apparatus shown in FIGS. 2 and 3.

{FIG. 5} FIG. 5 is a T-H graph showing the relationships for natural gas and nitrogen at a plurality of pressures.

{Description of Embodiments}

[0029] A schematic diagram showing the configuration of a floating liquefied-gas production facility including a liquefying apparatus according to an embodiment of the present invention will be described on the basis of FIG. 1. A floating liquefied-natural-gas production facility (floating LNG: FLNG) 1 includes a plurality of cargo tanks 2 in which liquefied natural gas (liquefied gas) is stored, a pretreatment apparatus 3, a liquefying apparatus (not shown), and a power supply apparatus (not shown) that supplies power to the floating liquefied-natural-gas production facility 1.

The floating liquefied-natural-gas production facility

(floating liquefied-gas production facility) 1 purifies and liquefies natural gas (gas to be liquefied), which is source gas venting from below strata on land or on the sea bed at high pressure, into liquefied natural gas (liquefied natural gas: LNG), i.e., the product, and is installed at the sea.

[0030] The cargo tanks (only three cargo tanks are shown in the diagram) 2 store the liquefied natural gas. The cargo tanks 2 are Moss self-supporting spherical tanks.

The pretreatment apparatus 3 removes impurities, such as carbon dioxide, hydrogen sulfide, water, and heavy components, contained in the natural gas, i.e., the source gas.

[0031] The liquefying apparatus liquefies natural gas by making the natural gas exchange heat with refrigerant (a heating medium for cooling). The liquefying apparatus is divided into a cold box 5 accommodating a high-pressure nitrogen heat exchanger (not shown) and a low-pressure nitrogen heat exchanger (not shown), which will be described below; an inboard power installation area 4 where a power supply apparatus for supplying power to the ship is provided; a liquefying-apparatus power unit area 6 accommodating a high-pressure nitrogen compressor (not shown), a low-pressure nitrogen compressor (not shown), a compressor-driving steam turbine (not shown), etc., which will be described below; and a storage area 7 where an end flash tank (not shown) (described below) etc. are provided.

[0032] The cold box 5 is provided above deck. The cold box 5 accommodates the high-pressure nitrogen heat exchanger (high-temperature-side-heating-medium heat exchanger) and the low-pressure nitrogen heat exchanger (low-temperature-side-heating-medium heat exchanger), which constitute part of the liquefying apparatus. The cold box 5 is heat-insulated to prevent transfer of heat to or from the outside.

The liquefying-apparatus power unit area 6 is provided below deck. The high-pressure nitrogen compressor (high-temperature-side-heating-medium compressor) and low-pressure nitrogen compressor (low-temperature-side-heating-medium compressor) constituting the liquefying apparatus, and the compressor-driving steam turbine (cross compound turbine) that drives these compressors are provided in the liquefying-apparatus power unit area 6.

[0033] The storage area 7, in which the end flash tank is provided, is provided below deck.

The inboard power installation area 4 is provided below deck and includes a boiler (not shown), a gas-fired diesel engine (not shown), and a gas-fired-diesel-engine-driven generator (not shown), which will be described below. The power required in the floating liquefied-natural-gas production facility 1 is supplied from these apparatuses provided in the inboard power installation area 4.

[0034] Next, the configuration of the liquefying apparatus according to this embodiment will be described using FIGS. 2 and 3.

FIG. 2 shows an enlarged diagram showing the configuration on the right side of the liquefying apparatus shown in FIG. 1, and FIG. 3 shows an enlarged diagram showing the configuration on the left side thereof.

The liquefying apparatus 10 mainly includes a high-pressure nitrogen heat exchanger 11, a low-pressure nitrogen heat exchanger 12, a high-pressure nitrogen compressor 13, a low-pressure nitrogen compressor 14, a compressor-driving steam turbine 15, a Joule-Thomson expansion valve (reducing valve) 16, the boiler (not shown), and an end flash tank 30. The liquefying apparatus 10 is divided into a refrigeration cycle and a driving section that drives the liquefying apparatus 10.

[0035] The refrigeration cycle includes a high-pressure nitrogen loop 17, in which high-pressure natural gas (at a pressure of, for example, from 15 MPa to 20 MPa) and nitrogen, which serves as refrigerant, exchange heat, and a low-pressure nitrogen loop 18, in which relatively low-pressure natural gas (at a pressure of, for example, 6 MPa or less) and nitrogen, which serves as refrigerant, exchange heat. These two refrigeration cycles form loops independent of each other.

The driving section includes the compressor-driving steam turbine 15.

[0036] The high-pressure nitrogen loop 17 mainly includes the high-pressure nitrogen heat exchanger 11, the high-pressure nitrogen compressor 13, and a high-pressure nitrogen expander 19.

The high-pressure nitrogen heat exchanger 11 performs heat exchange between the high-pressure natural gas and the nitrogen (hereinbelow, "high-pressure nitrogen"). For example, a stainless-steel-plate diffusion type heat exchanger (diffusion-bonded heat exchanger), of the plate type manufactured by Heatric, is suitably used as the high-pressure nitrogen heat exchanger 11.

[0037] The high-pressure nitrogen compressor 13 compresses high-pressure nitrogen (high-temperature-side heating medium). A high-pressure-turbine-side reduction gear 20 connected to the compressor-driving steam turbine 15 (described below) is connected to the high-pressure nitrogen compressor 13. The high-pressure nitrogen compressor 13 compresses the high-pressure nitrogen due to the high-pressure-turbine-side reduction gear 20 being driven.

[0038] The high-pressure nitrogen expander 19 expands the high-pressure nitrogen. A high-pressure-nitrogen booster 21 is connected to the high-pressure nitrogen expander 19. The high-pressure-nitrogen booster 21 is driven by the high-pressure nitrogen expander 19 being rotationally driven upon expanding the high-pressure nitrogen. The high-pressure-nitrogen booster 21 pressurizes the high-pressure nitrogen by being driven.

[0039] The low-pressure nitrogen loop 18 mainly includes the low-pressure nitrogen heat exchanger 12, the low-pressure nitrogen compressor 14, and a low-pressure nitrogen expander 22.

The low-pressure nitrogen heat exchanger 12 performs heat exchange between natural gas and nitrogen (here-

inbelow, "low-pressure nitrogen"). An aluminium brazed plate/fin-type heat exchanger is used as the low-pressure nitrogen heat exchanger 12.

[0040] The low-pressure nitrogen compressor 14 compresses low-pressure nitrogen (low-temperature-side heating medium). A low-pressure-turbine-side reduction gear 23 connected to the compressor-driving steam turbine 15 (described below) is connected to the low-pressure nitrogen compressor 14. The low-pressure nitrogen compressor 14 compresses the low-pressure nitrogen due to the low-pressure-turbine-side reduction gear 23 being driven.

[0041] The low-pressure nitrogen expander 22 expands the low-pressure nitrogen. A low-pressure-nitrogen booster 24 is connected to the low-pressure nitrogen expander 22. The low-pressure-nitrogen booster 24 is driven by the low-pressure nitrogen expander 22 being rotationally driven upon expanding the low-pressure nitrogen. The low-pressure-nitrogen booster 24 pressurizes the low-pressure nitrogen by being driven.

[0042] The compressor-driving steam turbine 15 is a large, cross-compound-type steam turbine, which is used in the main engine of a ship. A UST (ultra steam turbine) manufactured by Mitsubishi Heavy Industries, Ltd. is preferably used as the compressor-driving steam turbine 15.

The compressor-driving steam turbine 15 includes a high-pressure turbine 15a, an intermediate-pressure turbine (high-pressure turbine) 15b, a first low-pressure turbine 15c, and a second low-pressure turbine 15d. The high-pressure turbine 15a and the intermediate-pressure turbine 15b are provided on a primary shaft 15e (high-pressure-turbine-side shaft). The first low-pressure turbine (low-pressure turbine) 15c and the second low-pressure turbine (low-pressure turbine) 15d are provided on a secondary shaft (low-pressure-turbine-side shaft) 15f.

[0043] The high-pressure-turbine-side reduction gear 20 is connected to an end of the primary shaft 15e, and the low-pressure-turbine-side reduction gear 23 is connected to an end of the secondary shaft 15f.

The high-pressure-turbine-side reduction gear 20 transmits the output transmitted from the primary shaft 15e to the high-pressure nitrogen compressor 13. Thus, the high-pressure nitrogen compressor 13 is driven by the high-pressure turbine 15a or the intermediate-pressure turbine 15b being rotationally driven.

The low-pressure-turbine-side reduction gear 23 transmits the output transmitted from the secondary shaft 15f to the low-pressure nitrogen compressor 14. Thus, the low-pressure nitrogen compressor 14 is driven by the first low-pressure turbine 15c or the second low-pressure turbine 15d being rotationally driven.

[0044] The boiler (steam generating means) is a multi-fuel-fired boiler that uses liquefied natural gas, such as off-gas and boil-off gas (described below), and heavy oil as fuel.

The end flash tank 30 expands the liquefied natural gas that has passed through the high-pressure nitrogen cycle

17 and the low-pressure nitrogen cycle 18 to reduce the temperature thereof. The nitrogen component in the liquefied natural gas is removed in the end flash tank 30. Note that a reducing valve may be used instead of the end flash tank 30.

[0045] The Joule-Thomson expansion valve 16 is provided between the high-pressure nitrogen loop 17 and the low-pressure nitrogen loop 18. The Joule-Thomson expansion valve 16 allows the natural gas that has passed through the high-pressure nitrogen loop 17 to expand according to the Joule-Thomson effect via a throttle mechanism thereof.

[0046] Next, a method for liquefying natural gas will be described.

Natural gas, which is the source gas venting from below strata on land or on the sea bed, is guided to the pretreatment apparatus 3 provided above deck of the floating liquefied-natural-gas production facility 1 (see FIG. 1). Carbon dioxide, hydrogen sulfide, water, heavy components, etc. in the natural gas are removed in the pretreatment apparatus 3.

[0047] The natural gas purified by the pretreatment apparatus 3 is guided to the cold box 5. The natural gas guided to the cold box 5 is pressurized by a booster compressor 31 (see FIG. 2) or the like to, for example, 15 MPa or more. Note that it is desirable that the pressure be increased to 10 MPa or more.

[0048] The natural gas pressurized by the booster compressor 31 is guided to a first heat exchanger 32. The natural gas guided to the first heat exchanger 32 is cooled to, for example, 30 °C by heat exchange with sea water. The natural gas cooled by the first heat exchanger 32 is then guided to a second heat exchanger 33. The natural gas guided to the second heat exchanger 33 is cooled to, for example, -20 °C by heat exchange with fresh water, which serves as chiller water. By precooling the natural gas through the heat exchange with chiller water, it is possible to improve the heat exchange efficiency with the high-pressure nitrogen in the high-pressure nitrogen loop 17.

[0049] The natural gas precooled by the second heat exchanger 33 is guided to the high-pressure nitrogen loop 17. The natural gas guided to the high-pressure nitrogen loop 17 is guided to the high-pressure nitrogen heat exchanger 11 constituting the high-pressure nitrogen loop 17. The natural gas guided to the high-pressure nitrogen heat exchanger 11 exchanges heat with the high-pressure nitrogen in a first supercooling unit K1 provided in the high-pressure nitrogen heat exchanger 11. By exchanging heat with the high-pressure nitrogen in the first supercooling unit K1, the natural gas is cooled to, for example, -80 °C.

[0050] The cooled natural gas is guided to the Joule-Thomson expansion valve 16. The natural gas guided to the Joule-Thomson valve 16 expands (is reduced in pressure) to a pressure of, for example, 10 MPa by passing through the Joule-Thomson expansion valve 16. As a result, the natural gas that has passed through the Joule-

Thomson expansion valve 16 is cooled to, for example, -90 °C.

Note that it is desirable that the pressure of the natural gas be 10 MPa or less after being expanded by the Joule-Thomson expansion valve 16.

[0051] The natural gas that has expanded and been cooled by passing through the Joule-Thomson expansion valve 16 is guided to the low-pressure nitrogen loop 18. The natural gas guided to the low-pressure nitrogen loop 18 is guided to the low-pressure nitrogen heat exchanger 12 constituting the low-pressure nitrogen loop 18. The natural gas guided to the low-pressure nitrogen heat exchanger 12 exchanges heat with the low-pressure nitrogen in two stages. That is, the natural gas is cooled to, for example, -135 °C in a second supercooling unit K2 provided in the low-pressure nitrogen heat exchanger 12 and is then cooled to, for example, -160 °C in a third supercooling unit K3 provided in the low-pressure nitrogen heat exchanger 12, thereby being liquefied.

[0052] The liquefied natural gas liquefied in this way is guided to the end flash tank 30. The liquefied natural gas guided to the end flash tank 30 expands in the end flash tank 30 and is cooled, and the nitrogen component in the liquefied natural gas is released. The liquefied natural gas that has been further cooled and released the nitrogen component is guided to the cargo tanks 2 shown in FIG. 1, where it is stored.

[0053] A portion of the liquefied natural gas guided to the end flash tank 30 is gasified. The amount of gasified liquefied natural gas (hereinafter, "off-gas") is controlled to a flash rate of, for example, 10% or less by adjusting the temperature of the liquefied natural gas guided to the end flash tank 30.

[0054] The off-gas (for example, -140 °C) is guided from the end flash tank 30 to the low-pressure nitrogen heat exchanger 12. The off-gas guided to the low-pressure nitrogen heat exchanger 12 exchanges heat with the natural gas in the second supercooling unit K2 provided in the low-pressure nitrogen heat exchanger 12. As a result, the temperature of the off-gas becomes, for example, -100 °C. The off-gas is then guided to a second condensing unit G2 provided in the low-pressure nitrogen heat exchanger 12. The off-gas guided to the second condensing unit G2 exchanges heat with the low-pressure nitrogen (described below). The off-gas that has been subjected to heat exchange in the second condensing unit G2 is heated to, for example, 30 °C and is discharged from the low-pressure nitrogen heat exchanger 12.

[0055] Furthermore, boil-off gas, which is produced by a portion of the liquefied natural gas being gasified in the cargo tanks 2 (see FIG. 1), is also guided to the low-pressure nitrogen heat exchanger 12, similarly to the off-gas. The boil-off gas guided to the low-pressure nitrogen heat exchanger 12 is subjected to heat exchange in the second supercooling unit K2 and second condensing unit G2 provided in the low-pressure nitrogen heat exchanger 12 to be heated to, for example, 30 °C and is discharged

from the low-pressure nitrogen heat exchanger 12.

[0056] Next, the flow of the high-pressure nitrogen will be described.

The high-pressure nitrogen circulating in the high-pressure nitrogen loop 17 is compressed to, for example, 12 MPa and 120 °C by the high-pressure nitrogen compressor 13 driven by the high-pressure-turbine-side reduction gear 20. The high-pressure nitrogen that has been further pressurized is guided to a third heat exchanger 34. The high-pressure nitrogen guided to the third heat exchanger 34 is cooled to 85 °C by heat exchange with feedwater guided from a feedwater system (not shown).

[0057] The high-pressure nitrogen that has passed through the third heat exchanger 34 is then guided to a fourth heat exchanger 35. The high-pressure nitrogen guided to the fourth heat exchanger 35 is cooled to 40 °C by heat exchange with fresh water guided from a fresh water system (not shown). The high-pressure nitrogen cooled to 40 °C is guided to the high-pressure nitrogen heat exchanger 11. The high-pressure nitrogen guided to the high-pressure nitrogen heat exchanger 11 is guided to a first condensing unit G1 provided in the high-pressure nitrogen heat exchanger 11.

[0058] The high-pressure nitrogen guided to the first condensing unit G1 exchanges heat with the high-pressure nitrogen that has passed through the first supercooling unit K1 and expanded. As a result, the high-pressure nitrogen that has passed through the first condensing unit G1 is cooled to, for example, -25 °C. The high-pressure nitrogen that has been subjected to heat exchange in the first condensing unit G1 and cooled is guided to the high-temperature nitrogen expander 19. The high-pressure nitrogen guided to the high-temperature nitrogen expander 19 is expanded to, for example, 2 MPa and -85 °C. The high-pressure nitrogen that has expanded and been cooled is guided to the first supercooling unit K1 provided in the high-pressure nitrogen heat exchanger 11.

[0059] The expanded high-pressure nitrogen guided to the first supercooling unit K1 is heated to, for example, -30 °C by heat exchange with the above-mentioned natural gas. The high-pressure nitrogen heated in the first supercooling unit K1 is heated to, for example, 35 °C by heat exchange with the high-pressure nitrogen guided from the fourth heat exchanger 35 in the first condensing unit G1.

[0060] The high-pressure nitrogen that has been heated and expanded by passing through the first supercooling unit K1 and the first condensing unit G1 provided in the high-pressure nitrogen heat exchanger 11 is guided to the high-pressure-nitrogen booster 21. The expanded high-pressure nitrogen guided to the high-pressure-nitrogen booster 21 is pressurized to, for example, 3 MPa and 85 °C by the high-pressure-nitrogen booster 21 and is then guided to a fifth heat exchanger 36.

[0061] The high-pressure nitrogen pressurized and guided to the fifth heat exchanger 36 is cooled to, for example, 40 °C by heat exchange with fresh water guided

from the fresh water system. The high-pressure nitrogen that has been cooled upon passing through the fifth heat exchanger 36 is guided to the high-pressure nitrogen compressor 13.

5 In this manner, the high-pressure nitrogen circulates in the high-pressure nitrogen loop 17.

[0062] Next, the flow of the low-pressure nitrogen will be described.

10 The low-pressure nitrogen circulating in the low-pressure nitrogen loop 18 is compressed to, for example, 5 MPa by the low-pressure nitrogen compressor 14 driven by the low-pressure-turbine-side reduction gear 23. The compressed low-pressure nitrogen is guided to a sixth heat exchanger 37. The low-pressure nitrogen guided to the sixth heat exchanger 37 is cooled to, for example, 85 °C by heat exchange with feedwater guided from a feedwater system.

15 **[0063]** The low-pressure nitrogen that has passed through the sixth heat exchanger 37 is then guided to a seventh heat exchanger 38. The low-pressure nitrogen guided to the seventh heat exchanger 38 is cooled to, for example, 40 °C by heat exchange with feedwater guided from the feedwater system. The low-pressure nitrogen that has been cooled upon passing through the sixth heat exchanger 37 and the seventh heat exchanger 38 is guided to the low-pressure nitrogen heat exchanger 12. The low-pressure nitrogen guided to the low-pressure nitrogen heat exchanger 12 is guided to the second condensing unit G2 provided in the low-pressure nitrogen heat exchanger 12.

20 **[0064]** The low-pressure nitrogen guided to the second condensing unit G2 exchanges heat with the low-pressure nitrogen that has passed through the second supercooling unit K2 and expanded. As a result, the low-pressure nitrogen that has passed through the second condensing unit G2 is cooled to, for example, -90 °C. The low-pressure nitrogen that has been subjected to heat exchange in the second condensing unit G2 is guided from the low-pressure nitrogen heat exchanger 12 to the low-pressure nitrogen expander 22. The cooled low-pressure nitrogen guided to the low-pressure nitrogen expander 22 expands to, for example, 3 MPa and -164 °C. The low-pressure nitrogen that has expanded and been further cooled is guided to the third supercooling unit K3 provided in the low-pressure nitrogen heat exchanger 12.

25 **[0065]** The expanded low-pressure nitrogen guided to the third supercooling unit K3 is heated to, for example, -140 °C by heat exchange with the natural gas that has passed through the above-mentioned second supercooling unit K2. The expanded low-pressure nitrogen that has passed through the third supercooling unit K3 then exchanges heat with the natural gas guided from the Joule-Thomson expansion valve 16 to the low-pressure nitrogen heat exchanger 12 in the second supercooling unit K2. The low-pressure nitrogen that has exchanged heat with the natural gas and expanded is heated to, for example, -100 °C.

[0066] The low-pressure nitrogen that has passed through the second cooler K2 and expanded is then guided to the second condensing unit G2 provided in the low-pressure nitrogen heat exchanger 12. The expanded low-pressure nitrogen guided to the second condensing unit G2 exchanges heat with the low-pressure nitrogen guided from the seventh heat exchanger 38. As a result, the expanded low-pressure nitrogen is made to have a temperature of, for example, 36 °C and is discharged from the low-pressure nitrogen heat exchanger 12.

[0067] The low-pressure nitrogen that has been heated upon passing through the third supercooling unit K3, the second supercooling unit K2, and the second condensing unit G2 provided in the low-pressure nitrogen heat exchanger 12 is guided to the low-pressure-nitrogen booster 24. The expanded low-pressure nitrogen guided to the low-pressure-nitrogen booster 24 is pressurized to, for example, 1 MPa and 85 °C by the low-pressure-nitrogen booster 24. The pressurized low-pressure nitrogen is guided to an eighth heat exchanger 39.

[0068] The pressurized low-pressure nitrogen guided to the eighth heat exchanger 39 is cooled to, for example, 40 °C by heat exchange with feedwater guided from the feedwater system. The low-pressure nitrogen that has been cooled upon passing through the eighth heat exchanger 39 is guided to the low-pressure nitrogen compressor 14.

In this manner, the low-pressure nitrogen circulates in the low-pressure nitrogen loop 18.

[0069] Next, the flow of steam will be described.

Off-gas and boil-off gas discharged from the second condensing unit G2 provided in the low-pressure nitrogen heat exchanger 12 and heated to, for example, 30 °C are guided to the boiler. The off-gas and boil-off gas guided to the boiler are burned as fuel for the boiler, generating high-temperature, high-pressure (for example, 555 °C and 11 MPa) steam. The steam generated in the boiler is guided to the high-pressure turbine 15a of the compressor-driving steam turbine 15. The thermal energy of the steam guided to the high-pressure turbine 15a is transformed into rotation energy for the high-pressure turbine 15a, thereby rotationally driving the high-pressure turbine 15a. Due to the high-pressure turbine 15a being rotationally driven, the primary shaft 15e rotates. Due to the primary shaft 15e rotating, the intermediate-pressure turbine 15b and high-pressure-turbine-side reduction gear 20 provided on the primary shaft 15e are driven.

[0070] Meanwhile, the steam used to rotationally drive the high-pressure turbine 15a is made to have a pressure of, for example, 2 MPa and is discharged from the high-pressure turbine 15a. The steam discharged from the high-pressure turbine 15a is guided to a reheater (not shown). The steam guided to the reheater is transformed into reheat steam at a temperature of, for example, 555 °C by the reheater. This reheat steam is guided to the intermediate-pressure turbine 15b of the compressor-driving steam turbine 15.

[0071] The thermal energy of the reheat steam guided to the intermediate-pressure turbine 15b is transformed into rotation energy for the intermediate-pressure turbine 15b, thereby rotationally driving the intermediate-pressure turbine 15b. Due to the intermediate-pressure turbine 15b being rotationally driven, the primary shaft 15e rotates even more. Due to the primary shaft 15e rotating even more, the high-pressure-turbine-side reduction gear 20 provided on the primary shaft 15e is driven even more.

[0072] A portion of the steam is extracted from an intermediate stage of the intermediate-pressure turbine 15b. The extracted steam at a pressure of, for example, 1 MPa is used as high-pressure general service steam or the like for use in the floating liquefied-natural-gas production facility 1 (see FIG. 1).

The steam that has passed through all of the stages of the intermediate-pressure turbine 15b is made to have a temperature of, for example, 110 °C and is guided to the first low-pressure turbine 15c of the compressor-driving steam turbine 15.

[0073] The thermal energy of the steam guided to the first low-pressure turbine 15c is transformed into rotation energy for the first low-pressure turbine 15c, thereby rotationally driving the first low-pressure turbine 15c. Due to the first low-pressure turbine 15c being rotationally driven, the secondary shaft 15f rotates. Due to the secondary shaft 15f rotating, the second low-pressure turbine 15d and low-pressure-turbine-side reduction gear 23 provided on the secondary shaft 15f are driven.

[0074] A portion of the steam is extracted from an intermediate stage of the first low-pressure turbine 15c. The extracted steam at a pressure of, for example, 0.1 MPa, is used as low-pressure general service steam or the like for use in the floating liquefied-natural-gas production facility 1 (see FIG. 1).

The steam that has passed through all of the stages of the first low-pressure turbine 15c is guided to the second low-pressure turbine 15d provided on the secondary shaft 15f.

[0075] Furthermore, assist steam at a pressure of, for example, 0.6 MPa is separately supplied to the second low-pressure turbine 15d from an assist steam supply system (not shown). The second low-pressure turbine 15d is rotationally driven by the supplied assist steam. Due to the second low-pressure turbine 15d being rotationally driven, it is possible to drive the low-pressure-turbine-side reduction gear 23 connected to the secondary shaft 15f.

[0076] The steam that has passed through all of the stages of the first low-pressure turbine 15c and the assist steam that has driven the second low-pressure turbine 15d are guided to the main condenser (not shown), where they exchange heat with sea water and are transformed into condensed water.

[0077] In this way, in the compressor-driving steam turbine 15, it is possible to independently control the high-pressure-turbine-side reduction gear 20 and the low-

pressure-turbine-side reduction gear 23 with the primary shaft 15e and the secondary shaft 15f, and moreover, it is possible to independently control the low-pressure-turbine-side reduction gear 23 also by driving the second low-pressure turbine 15d with the assist steam.

[0078] Herein, T-H graphs of the natural gas and the nitrogen refrigerant in this embodiment will be described using FIG. 4 and the above-described FIG. 5.

FIG. 4 shows a T-H graph of the natural gas and the nitrogen refrigerant according to this embodiment.

In FIG. 4, the vertical axis shows heat load (kW), and the horizontal axis shows temperature (°C). The solid line in FIG. 4 shows natural gas pressurized to 15 MPa or 4 MPa, and the one-dot chain line shows nitrogen that exchanges heat with the natural gas pressurized to 4 MPa.

[0079] Furthermore, FIG. 5 shows a T-H graph showing the relationships for natural gas and nitrogen at a plurality of pressures.

In FIG. 5, the vertical axis shows heat load (kW), and the horizontal axis shows temperature (°C). The solid line in FIG. 5 shows natural gas pressurized to 15 MPa, the dashed line shows natural gas pressurized to 4 MPa, the one-dot chain line shows nitrogen that has a small temperature difference with respect to the natural gas at a relatively low-pressure, i.e., 4 MPa, and the two-dot chain line shows nitrogen that has a small temperature difference with respect to the natural gas at a high-pressure, i.e., 15 MPa.

[0080] As shown in FIG. 5, the natural gas at a pressure of 4 MPa (solid line) forms a step shape, indicating that almost no temperature change occurs in the process in which it is cooled by heat exchange with the nitrogen. Because the liquefaction efficiency of the natural gas is higher when the temperature difference between the natural gas and the nitrogen is smaller, the pinch point, at which the temperature difference between the nitrogen (dashed line) and the natural gas is smallest, forms a step shape. Therefore, the temperature difference between the natural gas and the nitrogen is large in the heat exchange process other than the step-shaped portion, and the overall liquefaction efficiency decreases.

[0081] When the natural gas is pressurized to a high pressure, for example, 15 MPa (dashed line), the step shape that appears when using the natural gas at 4 MPa disappears, and the temperature change of the natural gas becomes a substantially straight-line shape. Therefore, the temperature difference between the natural gas at 15 MPa and the nitrogen (two-dot chain line) decreases, and it is possible to perform efficient liquefaction over the entire range.

[0082] Note that, as shown in FIG. 5, at a low-temperature part of the natural gas, the temperature difference between the nitrogen and the natural gas, whether it is at a pressure of 15 MPa or at a pressure of 4 MPa, is small.

[0083] In this embodiment, as shown in FIG. 4, a substantially even temperature difference over the entire range of the heat exchange process is achieved by pres-

surizing the natural gas to a high pressure (for example, 15 MPa) and making it exchange heat with the nitrogen at a high-temperature part of the natural gas, and by pressurizing the natural gas to a relatively low pressure (for example, 4 MPa) and making it exchange heat with the nitrogen at a low-temperature part of the natural gas.

[0084] More specifically, at a high-temperature part of the natural gas, the high-pressure natural gas is made to exchange heat with the high-pressure nitrogen in the high-pressure nitrogen loop 17, and at a low-temperature part of the natural gas, the low-pressure natural gas is made to exchange heat with the low-pressure nitrogen in the low-pressure nitrogen loop 18.

Furthermore, the Joule-Thomson expansion valve 16 is provided between the high-pressure nitrogen loop 17 and the low-pressure nitrogen loop 18 to expand high-pressure natural gas at a pressure of 15 MPa to low-pressure natural gas at a pressure of 4 MPa. Thus, as shown in FIG. 4, it is possible to reduce the difference between the temperature of the natural gas at a high-pressure part and the temperature of the low-pressure natural gas at a pressure of 4 MPa, making the temperature change of the natural gas over the entire range have a substantially straight-line shape.

[0085] As has been described above, the liquefying apparatus 10 and the floating liquefied-natural-gas production facility 1 according to this embodiment provide the following advantages.

The high-pressure nitrogen composed of a single component (high-temperature-side heating medium) is guided to the high-pressure nitrogen heat exchanger (high-temperature-side-heating-medium heat exchanger) 11, the low-pressure nitrogen of the same type as the high-pressure nitrogen (low-temperature-side heating medium) is guided to the low-pressure nitrogen heat exchanger (low-temperature-side-heating-medium heat exchanger) 12, and the Joule-Thomson expansion valve (reducing valve) 16 that reduces the pressure of the natural gas (gas to be liquefied) to a predetermined pressure is provided between the high-pressure nitrogen heat exchanger 11 and the low-pressure nitrogen heat exchanger 12. With this configuration, it is possible to make the natural gas that has passed through the high-pressure nitrogen heat exchanger 11 approximate the temperature change of the low-pressure nitrogen by means of the Joule-Thomson expansion valve 16 and to guide the gas to the low-pressure nitrogen heat exchanger 12. Thus, the temperature difference between the natural gas and the high-pressure nitrogen during heat exchange and the temperature difference between the natural gas and the low-pressure nitrogen during heat exchange can be maintained substantially constant in the heat exchange process. Accordingly, it is possible to efficiently liquefy natural gas using the nitrogen (heating medium) composed of a single component.

[0086] The high-pressure nitrogen compressor (high-temperature-side-heating-medium compressor) 13 is connected to the primary shaft (high-pressure-turbine-

side shaft) 15e via the high-pressure-turbine-side reduction gear 20, and the low-pressure nitrogen compressor (low-temperature-side-heating-medium compressor) 14 is connected to the secondary shaft (low-pressure-turbine-side shaft) 15f via the low-pressure-turbine-side reduction gear 23. Because the primary shaft 15e and the secondary shaft 15f that constitute the compressor-driving steam turbine (cross compound turbine) 15 are separated from each other, it is possible to independently control the high-pressure nitrogen compressor 13 and the low-pressure nitrogen compressor 14 by independently controlling the high-pressure turbine 15a and the intermediate-pressure turbine (high-pressure turbine) 15b, which are connected to the primary shaft 15e, and the first low-pressure turbine (low-pressure turbine) 15c and the second low-pressure turbine (low-pressure turbine) 15d, which are connected to the secondary shaft 15f. Accordingly, it is possible to independently compress the high-pressure nitrogen and the low-pressure nitrogen and independently control the refrigeration load of the high-pressure nitrogen circulating in the high-pressure nitrogen loop 17 and that of the low-pressure nitrogen circulating in the low-pressure nitrogen loop 18.

[0087] A stainless-steel-plate diffusion type (plate type) heat exchanger is used as the high-pressure nitrogen heat exchanger 11 that performs heat exchange between the natural gas and the high-pressure nitrogen. Thus, it is possible to reduce the size of the high-pressure nitrogen heat exchanger 11. Accordingly, it is possible to make the cold box 5 accommodating the high-pressure nitrogen heat exchanger 11 constituting the liquefying apparatus 10 compact.

[0088] Furthermore, the pressure of the natural gas is reduced by allowing the gas to pass through the Joule-Thomson expansion valve 16, and an aluminium brazed plate/fin-type (plate type) heat exchanger is used as the low-pressure nitrogen heat exchanger 12. Therefore, it is also possible to reduce the size of the low-pressure nitrogen heat exchanger 12. Accordingly, it is possible to make the cold box 5 constituting the liquefying apparatus 10 even more compact.

[0089] A boiler (steam generating means) that generates steam by burning off-gas and boil-off gas in the liquefied natural gas as fuel is used. Thus, it is possible to generate the steam used to drive the compressor-driving steam turbine 15, using the off-gas and boil-off gas produced in the liquefied gas apparatus 10. Accordingly, it is possible to effectively utilize the off-gas and boil-off gas produced in the liquefying apparatus 10.

[0090] The liquefying apparatus 10 that is composed of the compressor-driving steam turbine 15 which is driven by steam is used in the floating liquefied-natural-gas production facility (floating liquefied-gas production facility) 1. Therefore, a cross-pound-type steam turbine, which is used for an existing marine main engine, may be used as the compressor-driving steam turbine 15. Thus, it is possible to effectively utilize an existing apparatus, without needing to develop a new compressor-driv-

ing steam turbine 15 that drives the high-pressure nitrogen compressor 13 and the low-pressure nitrogen compressor 14.

[0091] The liquefying apparatus 10 that includes the high-pressure nitrogen compressor 13, the low-pressure nitrogen compressor 14, the high-pressure nitrogen heat exchanger 11, and the low-pressure nitrogen heat exchanger 12, which use non-flammable nitrogen as the heating medium, is used in the floating liquefied-natural-gas production facility 1. Furthermore, the compressor-driving steam turbine 15 is used to drive the high-pressure nitrogen compressor 13 and the low-pressure nitrogen compressor 14. With this configuration, it is possible to prevent the risk of explosion caused by leakage of flammable gas from the heating medium etc. Thus, it is possible to dispose apparatuses, such as the high-pressure nitrogen compressor 13, the low-pressure nitrogen compressor 14, and the compressor-driving steam turbine 15, in the liquefying-apparatus power unit area 6 below deck in the floating liquefied-natural-gas production facility 1. Accordingly, it is possible to reduce the space for disposing the liquefying apparatus 10 above deck.

[0092] Although the heating medium used in the liquefying apparatus 10 has been described as nitrogen in this embodiment, any non-flammable heating medium may be used.

Although the gas to be liquefied has been described as liquefied natural gas (LNG) in this embodiment, liquefied petroleum gas (liquefied petroleum gas: LPG) or the like may also be used.

[0093] Although it has been described that the natural gas guided from the booster compressor 31 to the high-pressure nitrogen heat exchanger 11 is precooled by the first heat exchanger 32 and the second heat exchanger 33 in this embodiment, the present invention is not limited thereto; it is also possible that no precooling with chiller water is performed, i.e., no second heat exchanger 33 is provided. By performing precooling to a temperature of about -10 °C to -30 °C with chiller water, it is possible to increase the effect of reducing power to compress the high-pressure nitrogen and the low-pressure nitrogen guided to the high-pressure nitrogen loop 17 and the low-pressure nitrogen loop 18; but the precooling does not have to be performed.

[0094] Furthermore, it is possible that high-temperature exhaust gas discharged from the gas-fired diesel engine provided in the inboard power installation area 4 is guided to an exhaust heat recovery apparatus (not shown), such as an exhaust heat recovery boiler, to generate steam, and the steam generated by the exhaust heat recovery boiler is guided to the compressor-driving steam turbine 15, where it is used to start up the compressor-driving steam turbine 15. Thus, it is possible to effectively utilize the exhaust heat from the gas-fired diesel engine.

{Reference Signs List}

[0095]

- 1: floating liquefied-natural-gas production facility (floating liquefied-gas production facility) 5
 10: liquefaction facility
 11: high-pressure nitrogen heat exchanger (high-temperature-side-heating-medium heat exchanger)
 12: low-pressure nitrogen heat exchanger (low-temperature-side-heating-medium heat exchanger) 10
 16: Joule-Thomson expansion valve (reducing valve)

Claims

1. A liquefaction method wherein gas to be liquefied that has been subjected to heat exchange with a high-pressure heating medium composed of a single component is reduced in pressure, after which the gas to be liquefied that has been reduced in pressure is made to exchange heat with a low-temperature-side heating medium that is lower in temperature than and of the same type as the high-pressure heating medium. 20 25

2. A liquefying apparatus comprising:

a high-temperature-side-heating-medium heat exchanger that performs heat exchange between gas to be liquefied and a high-temperature-side heating medium; 30
 a reducing valve that reduces the pressure of the gas to be liquefied discharged from the high-temperature-side-heating-medium heat exchanger; and 35
 a low-pressure-heating-medium heat exchanger that performs heat exchange between the gas to be liquefied which has passed through the reducing valve and a low-temperature-side heating medium; wherein 40
 the high-temperature-side heating medium and the low-temperature-side heating medium are made of a single component and are of the same type, and 45
 the reducing valve reduces the pressure of the gas to be liquefied that will be guided to the low-temperature-side-heating-medium heat exchanger to a predetermined pressure. 50

3. The liquefying apparatus according to Claim 2, comprising:

a cross compound turbine including 55
 a high-pressure turbine that is driven by steam guided thereto,

a high-pressure-turbine-side shaft that is connected to the high-pressure turbine, a low-pressure turbine that is driven by the steam discharged from the high-pressure turbine and guided thereto, and a low-pressure-turbine-side shaft that is connected to the low-pressure turbine;

a high-temperature-side-heating-medium compressor that compresses a high-temperature-side heating medium guided to the high-temperature-side-heating-medium heat exchanger; a low-temperature-side-heating-medium compressor that compresses a low-temperature-side heating medium guided to the low-temperature-side-heating-medium heat exchanger; and a steam generating means that generates steam to be guided to the high-pressure turbine, wherein the high-temperature-side-heating-medium compressor is connected to the high-pressure-turbine-side shaft, and the low-temperature-side-heating-medium compressor is connected to the low-pressure-turbine-side shaft.

4. The liquefying apparatus according to Claim 2 or 3, wherein the high-temperature-side-heating-medium heat exchanger is of a plate type.
 5. The liquefying apparatus according to any one of Claims 2 to 4, wherein the steam generating means generates steam by using off-gas in the liquefied gas as fuel.
 6. A floating liquefied-gas production facility comprising the liquefying apparatus according to any one of Claims 2 to 5.
 7. The floating liquefied-gas production facility according to Claim 6, wherein the high-temperature-side heating medium and the low-temperature-side heating medium employ nitrogen.

FIG. 1

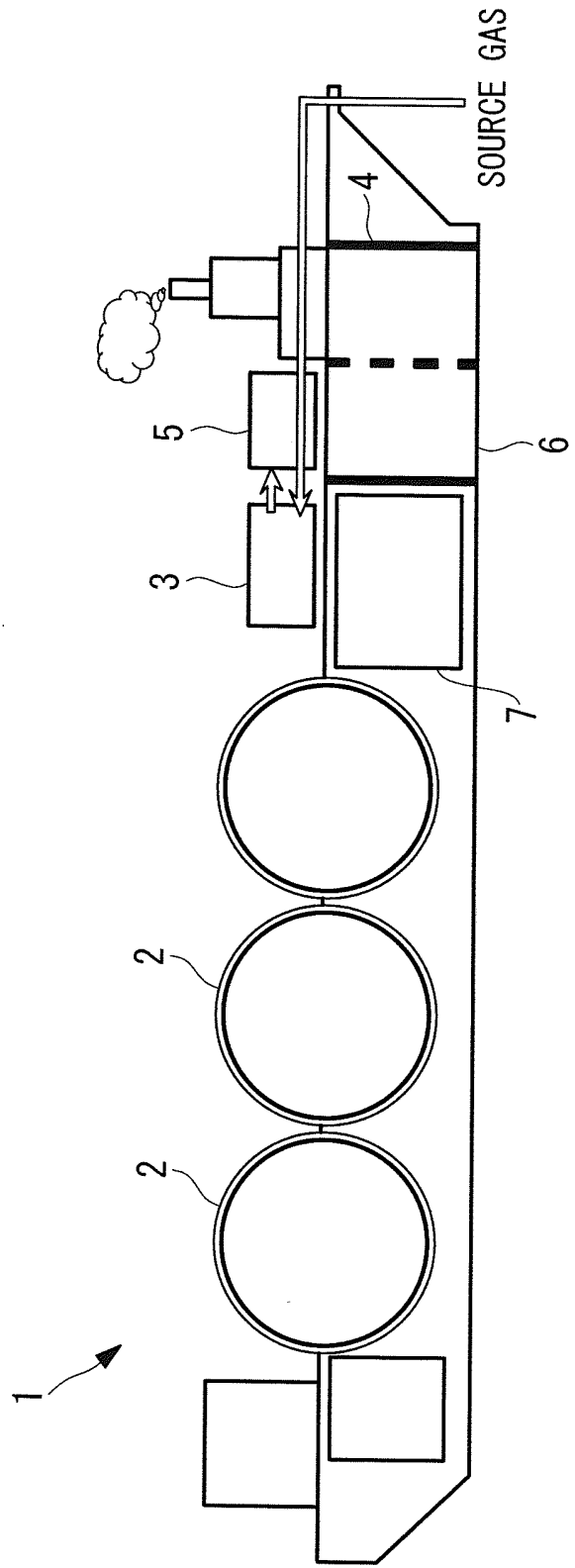


FIG. 2

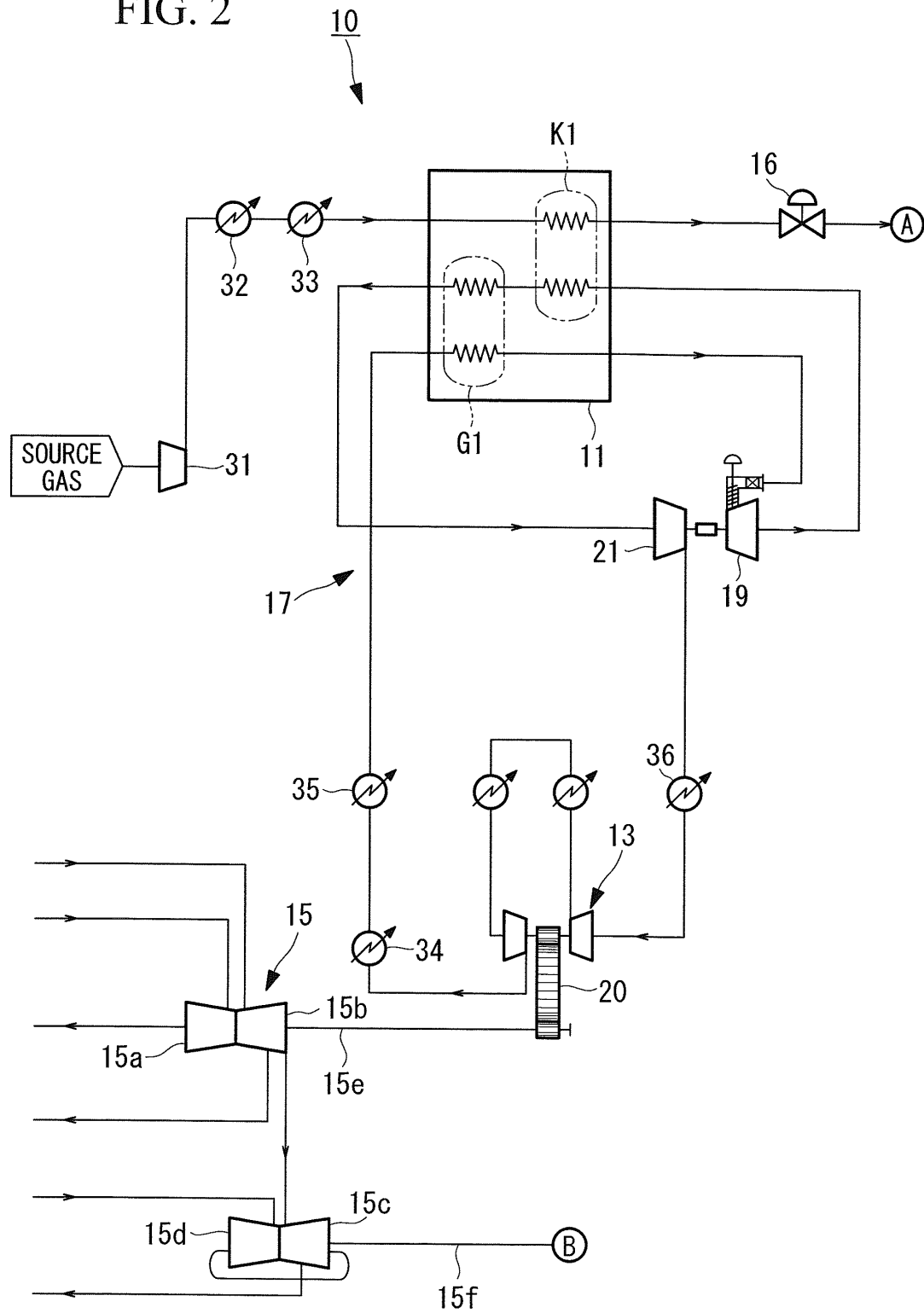


FIG. 3

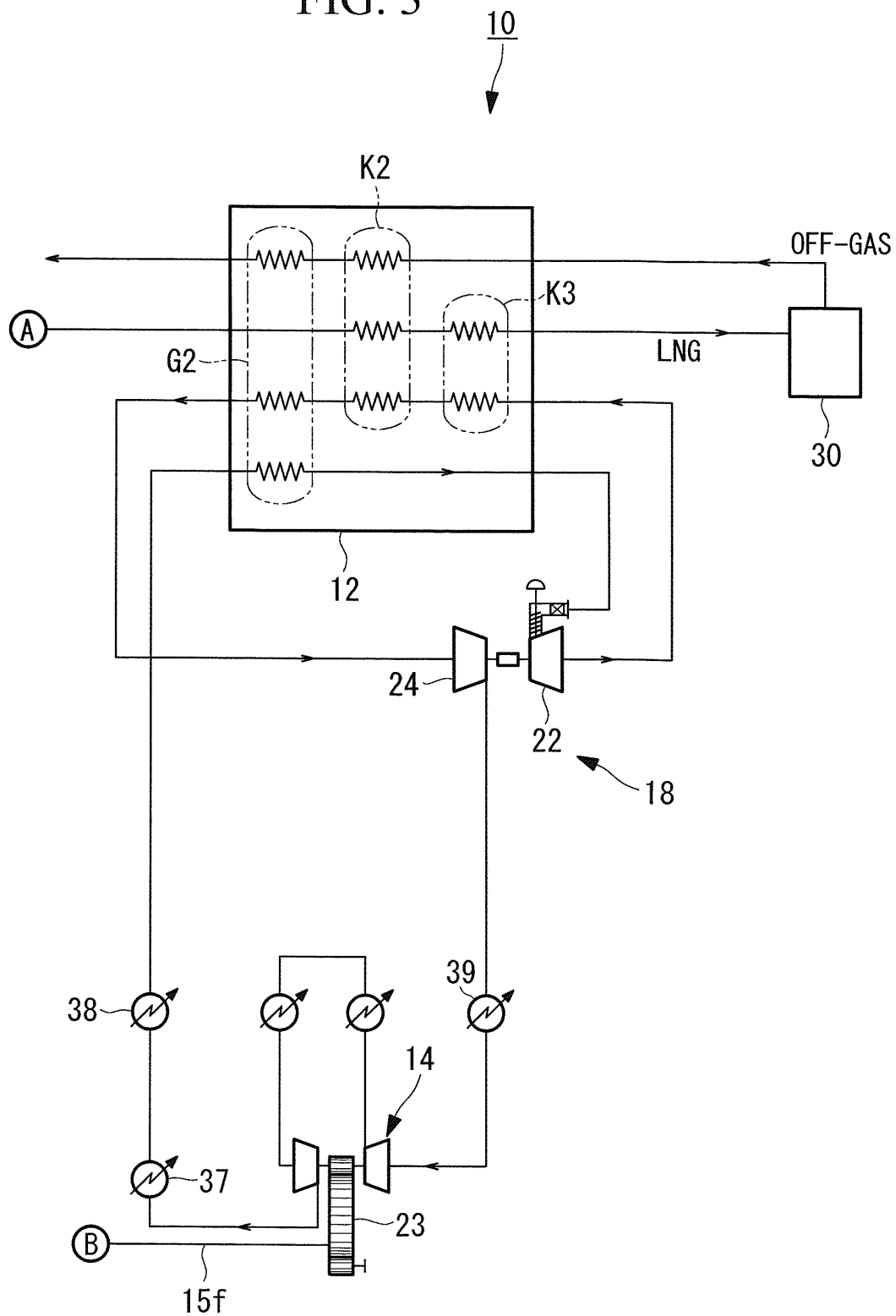


FIG. 4

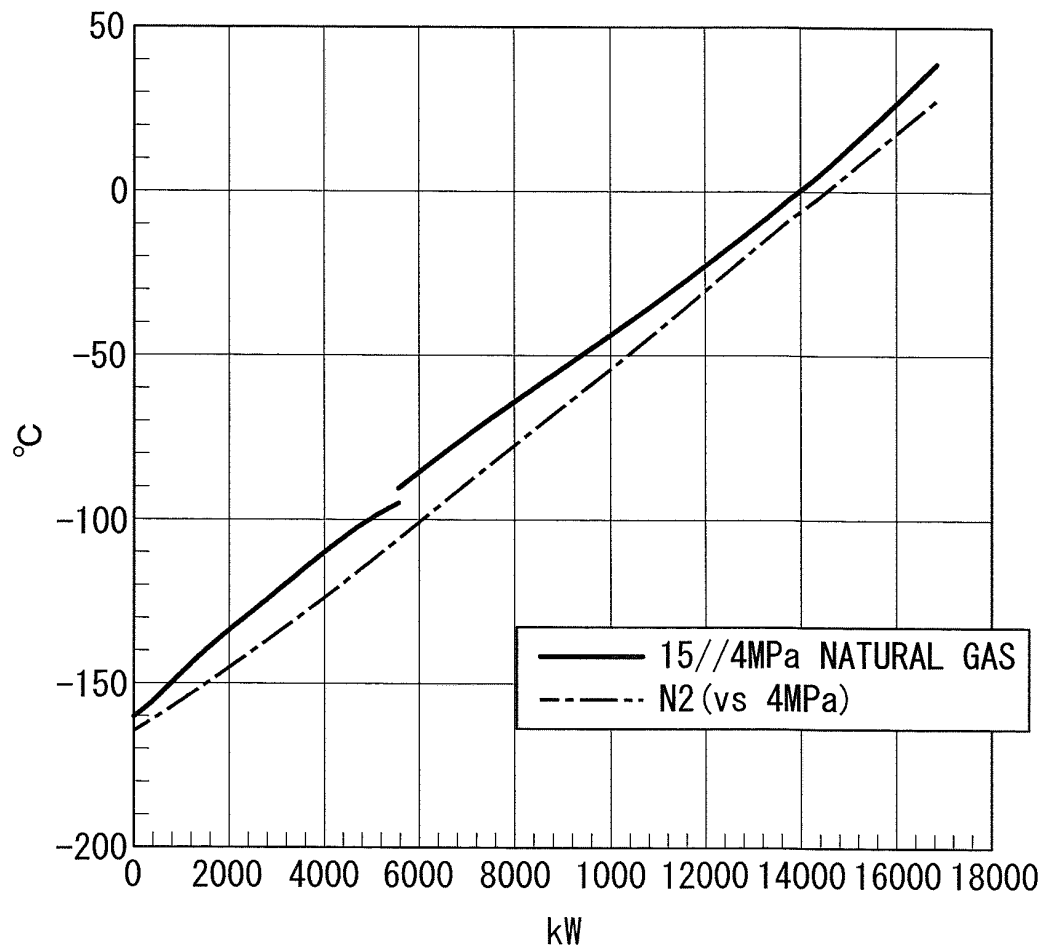
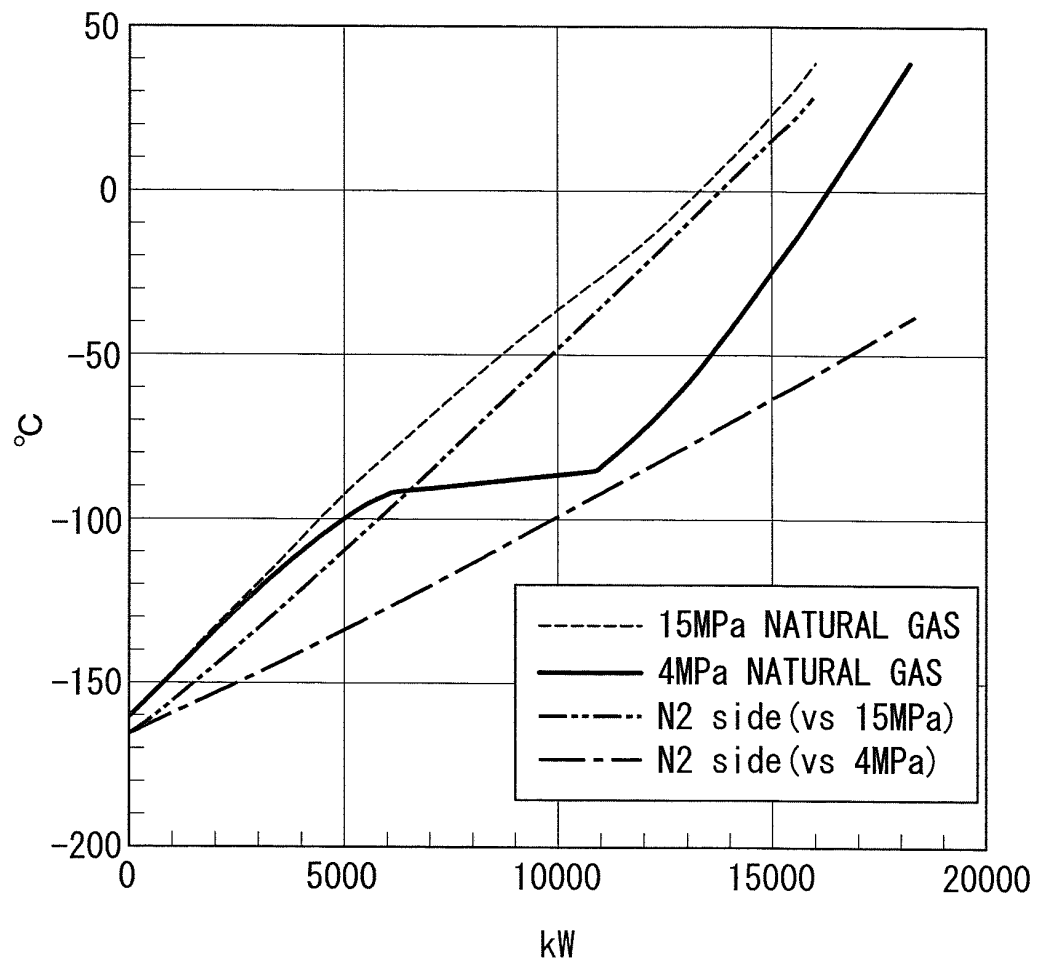


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/073255

A. CLASSIFICATION OF SUBJECT MATTER

F25J1/00(2006.01) i, B63B35/44(2006.01) i, C10L3/06(2006.01) i

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)

F25J1/00

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

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2012

Kokai Jitsuyo Shinan Koho 1971-2012 Toroku Jitsuyo Shinan Koho 1994-2012

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2001-526376 A (BHP Petroleum Pty. Ltd.), 18 December 2001 (18.12.2001), entire text; all drawings & US 6446465 B1 & GB 9726297 A & EP 1038146 A1 & WO 1999/030094 A1 & AU 752201 B	1-7
A	EP 1895254 A1 (SHELL INTERNATIONALE RESEARCH), 05 March 2008 (05.03.2008), entire text; all drawings (Family: none)	1-7

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
13 January, 2012 (13.01.12)Date of mailing of the international search report
24 January, 2012 (24.01.12)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/073255

<1>

There is a term "a high-pressure heating medium" in the claims and the description. However, there is found no statement about the definition of the term (e.g., against what the pressure is high, in what system the pressure is high, or the like) and, therefore, the meaning of the term is unclear (the present search report was prepared on the assumption that the term is a typographical error and is correctly to read "a higher-temperature-side heating medium").

<2>

In claim 2, there is a term "a heat exchanger for low-pressure heating media". However, there is found no statement about the definition of the term in the description and, therefore, the meaning of the term is unclear (the present search report was prepared on the assumption that the term is a typographical error and is correctly to read "a heat exchanger for lower-temperature-side heating media").

<3>

In the description, only the following method or facility for liquefying a natural gas is disclosed specifically as an specific example of the inventions described in claims 1-7: a method or facility for liquefying a natural gas, in which the natural gas is passed through a heat exchanger for higher-temperature-side heating media to cause the heat exchange between the natural gas and a higher-temperature-side heating medium composed only of nitrogen and then is cooled, the pressure of the cooled natural gas is reduced, and the natural gas having a reduced pressure is passed through a heat exchanger for lower-temperature-side heating media to cause the heat exchange between the natural gas and a lower-temperature-side heating medium composed only of nitrogen and is then cooled, whereby the natural gas is liquefied, wherein the higher-temperature-side heating medium is compressed by means of a compressor for higher-temperature-side heating media, is then expanded, and is then introduced into the heat exchanger for higher-temperature-side heating media, and wherein the lower-temperature-side heating medium is compressed by means of a compressor for lower-temperature-side heating media, is then expanded, and is then introduced into the heat exchanger for lower-temperature-side heating media.

It is difficult to expand the above-mentioned specific example to the whole of the invention described in claims 1-7 in which the structure of a cooling medium circuit, the gas to be liquefied, the heating medium and the like are not specified, even though the statements of paragraphs [0009] and [0078]-[0083] in the description and a matter that it is difficult to find a combination of the gas to be liquefied and the heating medium which has high heat exchange efficiency by employing multiple pressures are taken into consideration.

Consequently, the inventions described in claims 1-7 are not supported in the meaning within PCT Article 6.

Such being the case, the present search report was prepared on parts of the inventions described in claims 1-7 which are included within the scope of the above-mentioned specific example.

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2006504928 A [0003]
- JP 2006503252 A [0003]