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(54) **OXYGEN LIQUEFACTION PROCESS**

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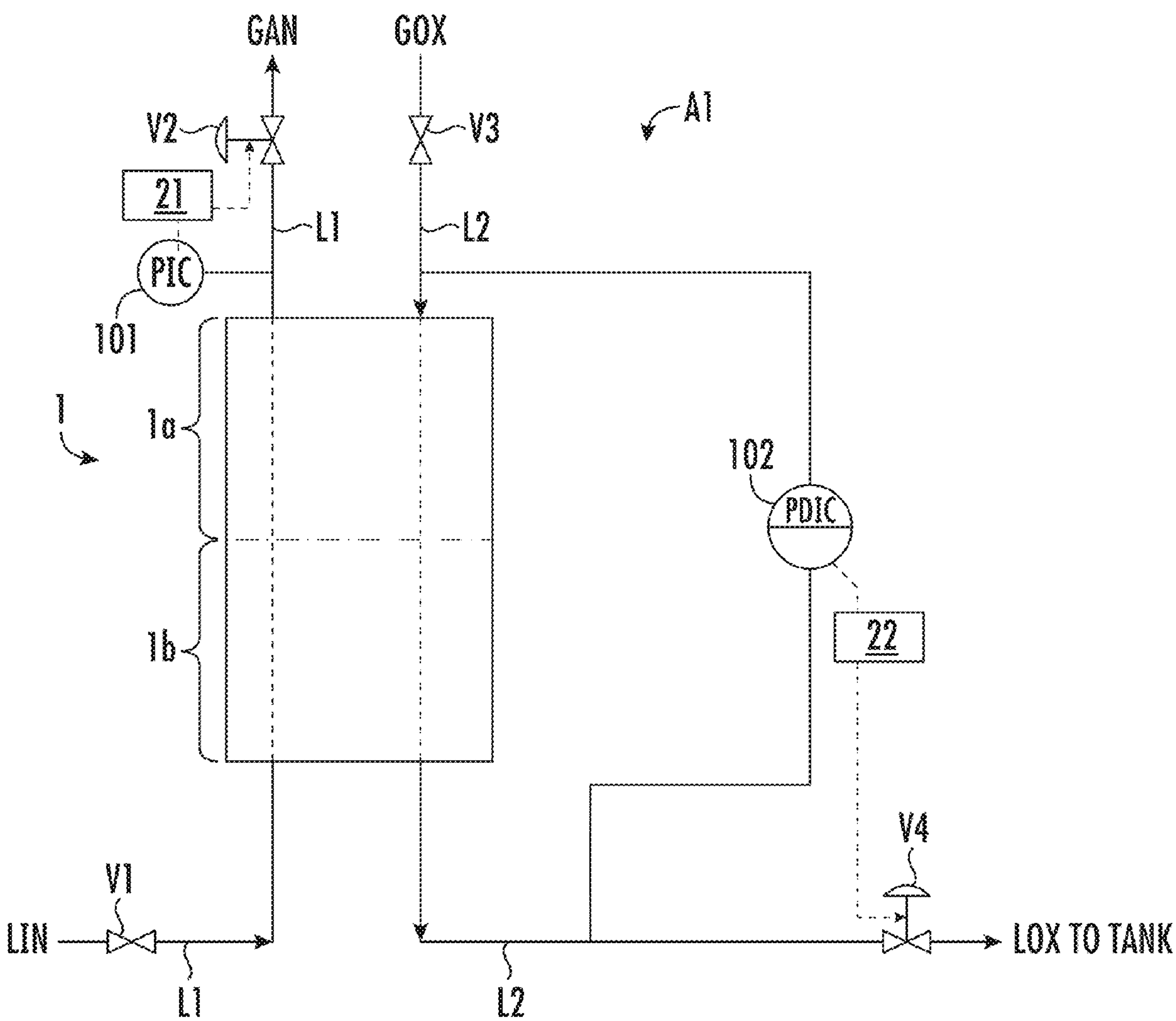
(57) **ABSTRACT**

An oxygen liquefaction apparatus may include a heat exchanger that allows oxygen gas to be cooled and condensed with liquid nitrogen. The oxygen liquefaction apparatus may include: a differential pressure gauge that measures the difference in pressure between the hot and cold ends of an oxygen flow path; and an oxygen control unit that calculates the level of oxygen inside the heat exchanger based on the differential pressure gauge reading, that controls an oxygen control valve to adjust the level, and that controls the heat transfer area to control the condensation of the oxygen.



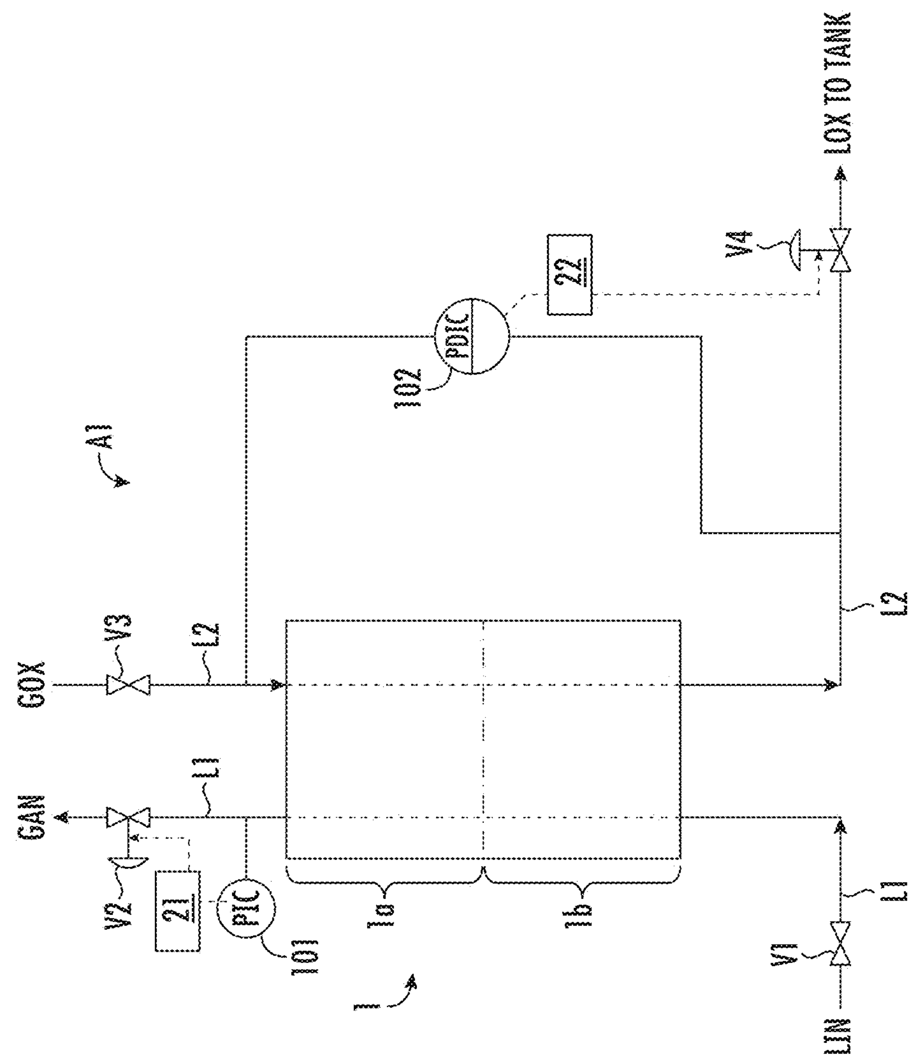
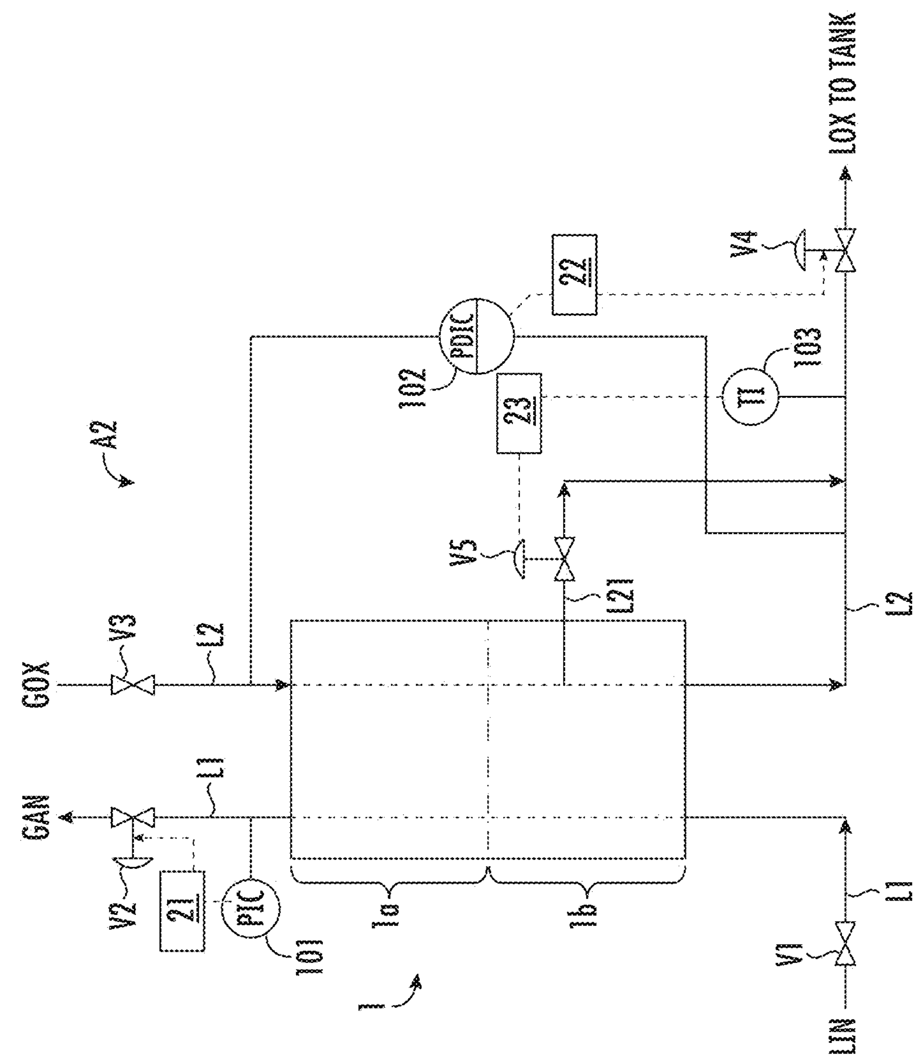

GAN
GOX
V3
L2
L1
V2
21
PIC
101
1a
1b
1
V1
LIN
L1
L2
A1
102
PDIC
22
V4
LOX TO TANK

FIG. 1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V2
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V1
LIN
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V5
L21
23
102
PDIC
22
V4
TI
103
L2
LOX TO TANK

FIG. 2

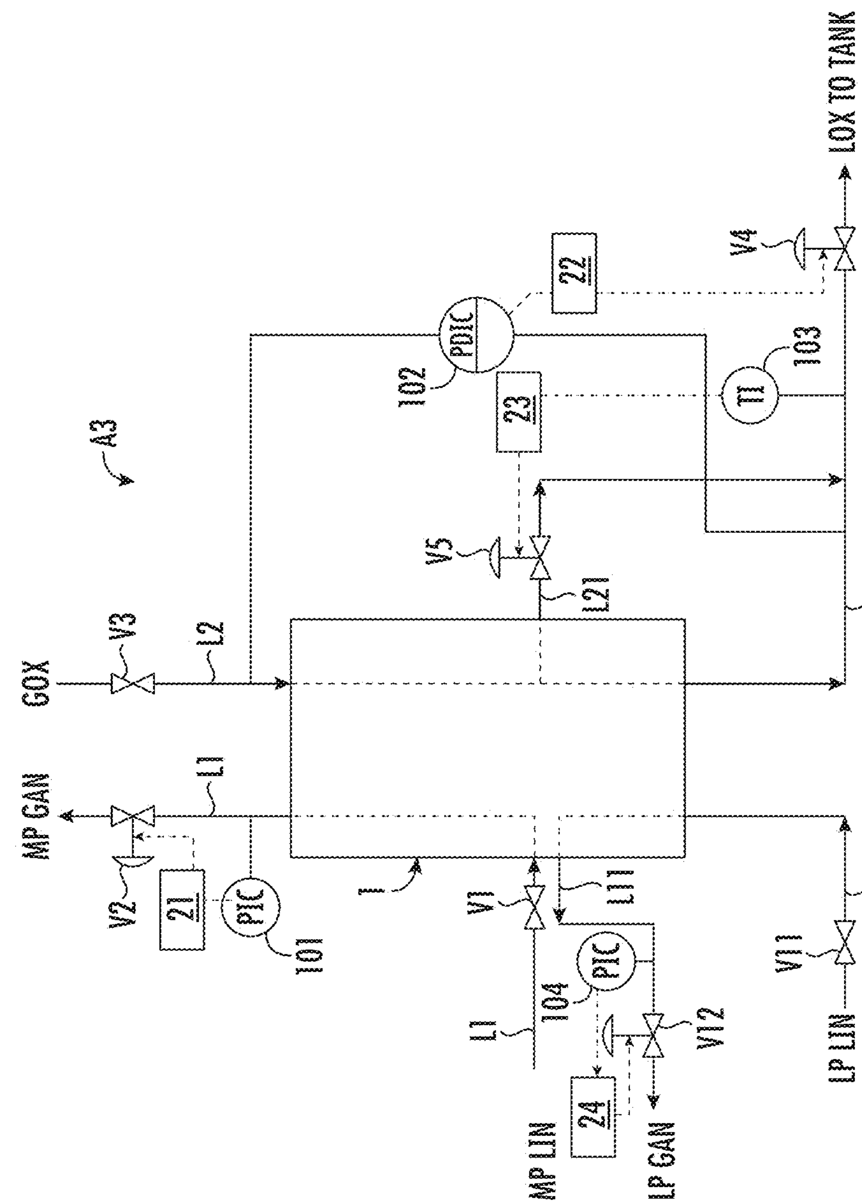
A3
MP GAN
GOX
V3
L2
L1
V2
21
PIC
101
I
V1
L11
V11
LP LIN
PIC
104
V12
L1
MP LIN
24
LP GAN
V5
L21
PDIC
102
22
23
TI
103
V4
LOX TO TANK
L2

FIG. 3

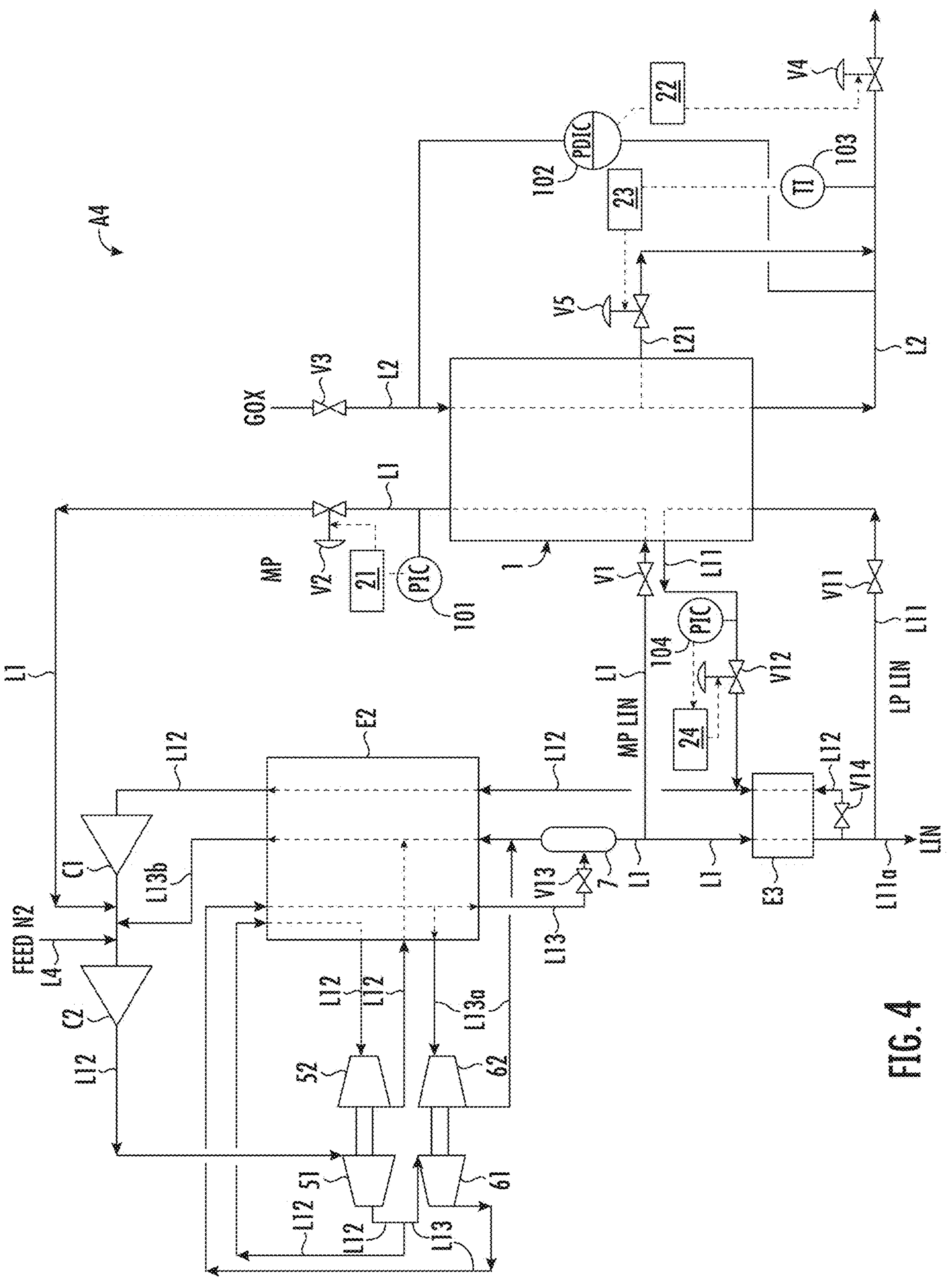
A4
GOX
V3
L2
L1
MP
V2
21
PIC
101
1
V1
L11
PDIC
102
22
23
V4
V5
L21
TI
103
104
V12
24
MP LIN
LP LIN
V11
E2
L12
FEED N2
L4
C1
C2
L13b
L13
V13
7
E3
V14
L11a
LIN
L13a
52
62
51
61

FIG. 4

# OXYGEN LIQUEFACTION PROCESS

## CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit of priority under 35 U.S.C. § 119 (a) and (b) to Japanese patent application No. JP2024-019249, filed Feb. 13, 2024, which is herein incorporated by reference in its entirety.

## FIELD OF THE INVENTION

**[0002]** The present disclosure relates to a liquefaction apparatus for liquefying oxygen gas or argon gas, for example, as well as to a liquefied product production method.

## BACKGROUND OF THE INVENTION

**[0003]** Liquefied oxygen can be supplied directly from an air separation apparatus, and can also be obtained by cooling and liquefying by-product oxygen from oxygen pipelines or water electrolysis apparatus.

**[0004]** In JP 2961072 B2 and CN 113375420 A1, for example, oxygen is liquefied using liquefied nitrogen or a nitrogen liquefaction cycle. In Patent Document JP 3306668 B2, liquefied air supplied from an air separation apparatus is used to liquefy oxygen.

**[0005]** However, in contrast to oxygen gas products, which are continually supplied via pipelines, it would be more desirable to be able to adjust liquefied oxygen production volume depending on demand and transportation conditions. The installation of a liquefier or an air separation apparatus capable of liquefaction would entail substantial capital investment in order to meet intermittent demand, and it would therefore be more reasonable for oxygen to be liquefied with a simple equipment configuration using refrigerant that is readily available, such as commercially available liquefied nitrogen.

## SUMMARY OF THE INVENTION

**[0006]** Before being stored, liquefied oxygen is subcooled to a temperature below its boiling point. This is to prevent the liquefied oxygen from evaporating off as a result of heat coming in from the storage tank environment or drops in pressure when loaded into storage tanks. However, excessive cooling of liquefied oxygen may result in lower pressure inside the storage tank, making it important to produce liquefied oxygen at a suitable temperature.

**[0007]** Owing to differences between the physical properties of the liquefied oxygen and the liquefied nitrogen serving as the refrigerant, however, liquefied oxygen is not readily produced at a suitable temperature simply by being cooled with liquefied nitrogen in a heat exchanger, and the liquefied oxygen may very well end up being overcooled. Specifically, there is a need to develop control technology for efficiently obtaining liquefied oxygen product at a suitable temperature.

**[0008]** When oxygen gas is liquefied with a single heat exchanger, three different cooling modes comprising the cooling, condensation, and subcooling of the gas in the heat exchanger must be controlled, yet the nitrogen serving as the refrigerant is also subject to similar changes in temperature and phase, thus making it difficult for the oxygen to be liquefied in a stable manner. Particularly when oxygen gas is a by-product, the flow rate is not always stable and therefore tends to be less amenable to adjustment. The above problems apply equally to argon, the boiling point of which is close to that of oxygen.

**[0009]** An object of the present disclosure is to provide a liquefaction apparatus that allows a liquefied product of suitable temperature to be efficiently supplied.

**[0010]** Another object of the present disclosure is to provide a liquefied product production method.

**[0011]** The liquefaction apparatus of the present disclosure comprises a heat exchanger (**1**) whereby a gas (oxygen gas or argon gas) can be cooled and condensed with a refrigerant (such as liquefied nitrogen) (and furthermore subcooled with a separate liquefied nitrogen).

**[0012]** From the hot end toward the cold end of the heat exchanger (**1**), there are two sections that, in terms of heat exchange functions, are a cooling and condensing area (**1***a*) and a subcooling area (**1***b*), where the size of the areas is not fixed but varies, depending on the relationship between the refrigerant and the gas that is to be treated. The structure of the liquefaction apparatus is such that condensation and subcooling are controlled by tracking the level of the liquid in the subcooling area (**1***b*).

**[0013]** The liquefaction apparatus may comprise a differential pressure gauge (**102**) for measuring the difference in pressure between the hot and cold ends of a path through which flows the gas to be liquefied (such as oxygen or argon).

**[0014]** The liquefaction apparatus may furthermore comprise a differential pressure gauge for measuring the difference in pressure between the hot and cold ends of a refrigerant flow path.

**[0015]** The liquefaction apparatus may comprise a liquefied product control unit (**22**) that: calculates the level of the liquefied product (such as liquefied oxygen or liquefied argon) inside the heat exchanger (**1**) based on the reading of the differential pressure gauge (**102**) of the path through which flows the gas to be liquefied; controls a liquefied product control valve (V**4**) to adjust the level; and controls the heat transfer area to control the condensation of the gas (such as oxygen gas or argon gas).

**[0016]** The liquefaction apparatus may comprise a liquefied product control unit that: calculates the level of refrigerant (such as liquefied nitrogen) inside the heat exchanger (**1**) based on the reading of the differential pressure gauge of the refrigerant flow path; controls the liquefied product control valve V**4** to adjust the level; and controls the heat transfer area to control the condensation of the gas (such as oxygen gas or argon gas).

**[0017]** The liquefied product control unit may control the liquefied product control valve based on the level of the refrigerant and the level of the liquefied product of the gas to adjust the levels, and control the heat transfer area to control the condensation of the gas.

**[0018]** The structure of the differential pressure gauge may be such that the difference in pressure is calculated based on the difference between pressure gauges disposed at both the hot and the cold ends and the readings of said pressure gauges, and may be such that the difference in pressure is calculated based on the pressure gauge readings or the pressure gauges.

**[0019]** The liquefaction apparatus may comprise a liquefied product bypass line (L**21**) that discharges liquefied product from a part of the liquified product e flow path inside the heat exchanger (**1**) that is lower than the level of the liquefied product, and that merges with the liquefied product discharge line through which the product is discharged from the cold end of the heat exchanger (**1**).

**[0020]** The apparatus may comprise a bypass control unit (**23**) that controls the opening and closing of a bypass control valve (V**5**) disposed on the liquefied product bypass line (L**21**) so that the temperature of the liquefied product (such as liquefied oxygen or liquefied argon) is at a specified value.

**[0021]** This structure allows the condensation and subcooling of the gas to be controlled with even a single heat exchanger, thus allowing liquefied products (such as liquefied oxygen and liquefied argon) that have a stable temperature to be produced at a low cost.

**[0022]** The structure of the liquefied product bypass line (L**21**) is not limited to one, but may have two or more lines, wherein the liquefied product is taken out from the path through which flows the gas inside the heat exchanger (**1**).

**[0023]** The liquefied product production method of the present disclosure is a method in which a gas is introduced through the hot end of the heat exchanger (**1**), the liquefied product is discharged from the cold end, a refrigerant (such as liquefied nitrogen) is introduced through the cold end of the heat exchanger (**1**), and the refrigerant gas is discharged from the hot end, thereby producing a liquefied product from the gas that is to be treated, said method comprising a discharge amount control step for controlling the amount of discharged liquefied product based on the level of liquefied product in the heat exchanger (**1**).

**[0024]** The production method may furthermore comprise a discharge amount control step for controlling the amount of discharged liquefied product based on the level of refrigerant in the heat exchanger (**1**).

**[0025]** The level of the liquefied product may, for example, be calculated based on the difference in pressure of the path through which flows the liquified product inside the heat exchanger (**1**).

**[0026]** The level of the refrigerant may, for example, be calculated based on the difference in pressure of the refrigerant path inside the heat exchanger (**1**).

**[0027]** The liquefied product production method may comprise a temperature adjustment step in which a portion of the liquefied product (liquefied product that is warmer than the liquefied product discharged from the cold end) is discharged from a part of the heat exchanger (**1**) that is lower than the level of the liquefied product, and is merged with liquefied product that is taken out as the final product, so as to adjust the temperature of the liquefied product.

**[0028]** In cases where a long residence time in the subcooling area (**1***b*) results in a long cooling time and too low of a temperature, liquefied product can be taken out from an area where the cooling time is shorter than the subcooling area (**1***b*) (location closer to the hot end than the cold end) and can be merged with the liquefied product to adjust the temperature.

**[0029]** The liquefied product production method may comprise a subcooling step in which a primary refrigerant, that primarily effects cooling and condensation, as well as a second refrigerant, that has a lower pressure than the first refrigerant, are supplied to the heat exchanger (**1**), and the liquefied product is subcooled by the second refrigerant, which has lower pressure.

**[0030]** This will allow the first refrigerant to be used to cool and condense (liquefy) the gas that is to be treated, and will allow the second refrigerant that has lower pressure to be used to subcool the liquefied product.

**[0031]** The liquefied product production method may comprise a first refrigerant gas introduction step in which a first refrigerant gas obtained by gasifying the first refrigerant in the heat exchanger (**1**) is introduced into the intake side of the recycling compressor (C**1**) or feed compressor (C**2**) of a refrigerant liquefier (E**2**); and a second refrigerant gas introduction step in which a second refrigerant gas obtained by gasifying the second refrigerant in the heat exchanger (**1**) is introduced into the cold end, or the intake side of the recycling compressor (C**1**) or feed compressor (C**2**), of the refrigerant liquefier (E**2**).

**[0032]** The liquefied product production method may comprise a control step for controlling a flow rate control means (V**4**) (such as a restricted orifice) disposed in the liquefied product line (L**2**) through which flows the liquefied product discharged from the cold end of the heat exchanger (**1**).

**[0033]** This makes it possible to balance the pressure with the control pressure loss in the flow control valve (V**5**) of the liquefied product bypass line (L**21**) by which liquefied product is discharged from a part of the liquified product flow path inside the heat exchanger (**1**) that is lower than the level of the liquefied product, and thereby prevent excessive cooling of the liquefied product in the subcooling area (**1***b*).

**[0034]** The liquefaction apparatus (A**1**, A**2**, A**3**, A**4**) of the present disclosure may comprise: a heat exchanger (**1**), a nitrogen line (L**1**) for introducing liquefied nitrogen (LIN) as a refrigerant from the cold end of the heat exchanger (**1**) and for discharging nitrogen gas (GAN) from the hot end, an oxygen line (L**2**) for introducing oxygen gas (GOX) to be liquified through the hot end of the heat exchanger (**1**) and for discharging liquefied oxygen (LOX) from the cold end, a nitrogen gas pressure measuring unit (**101**) for measuring the pressure of the nitrogen gas downstream from the cold end of the heat exchanger (**1**) in the nitrogen line (L**1**), a nitrogen control unit (**21**) that controls a nitrogen control valve (V**2**) disposed in the nitrogen line (L**1**) based on the pressure value measured by the nitrogen gas pressure measurement unit (**101**) (for example, when within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value), an oxygen differential pressure measuring unit (**102**) for measuring the difference in pressure between the oxygen gas pressure upstream from the hot end of the heat exchanger (**1**) of the oxygen line (L**2**) and the liquefied oxygen pressure downstream from the cold end of the heat exchanger (**1**) of the oxygen line (L**2**), and an oxygen control unit (**22**) that controls an oxygen control valve (V**4**) disposed in the oxygen line (L**2**) based on the pressure difference measured by the oxygen differential pressure measurement unit (**102**) (for example, when within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value).

**[0035]** The oxygen liquefaction apparatus (A**1**, A**2**, A**3**, A**4**) may comprise: a valve (V**1**) disposed upstream from the cold end of the heat exchanger (**1**) of the oxygen line (L**1**), and a valve (V**3**) disposed upstream from the hot end of the heat exchanger (**1**) of the oxygen line (L**2**).

**[0036]** The structure of the oxygen differential pressure measuring unit (**102**) may be such that the difference in pressure is calculated based on the difference between pressure gauges disposed at both the hot and the cold ends and the readings of said pressure gauges, and may be such that the difference in pressure is calculated based on the oxygen differential pressure measuring unit (**102**) readings or the pressure gauges.

**[0037]** The oxygen liquefaction apparatus (A**2**, A**3**, A**4**) may comprise: a liquefied oxygen bypass line (L**21**) by which a portion of the hot liquefied oxygen is discharged from a point midway in the heat exchanger (**1**) (liquefied oxygen that is warmer than the liquefied oxygen discharged from the cold end) and is merged with liquefied product downstream from the cold end of the heat exchanger (**1**) of the oxygen line (L**2**) so as to adjust the temperature of the liquefied oxygen taken out as the final product, a liquefied oxygen temperature measurement unit (**103**) for measuring the temperature of liquefied oxygen downstream from the cold end of the heat exchanger (**1**) of the oxygen line (L**2**), and a hot liquefied oxygen control unit (**23**) that controls a hot liquefied oxygen control valve (V**5**) disposed in the liquefied oxygen bypass line (L**21**) based on the temperature measured by the liquefied oxygen temperature measurement unit (**103**) (for example, when within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value).

**[0038]** The oxygen liquefaction apparatus (A**3**, A**4**) may comprise: a low-pressure nitrogen line (L**11**) for introducing low-pressure liquefied nitrogen (LP LIN) through the cold end of the heat exchanger (**1**), and discharging low-pressure nitrogen gas from a point midway in the heat exchanger (**1**) (border between the subcooling area (**1***b*) and the condensation area (**1***a*), or neighbourhood thereof), a low-pressure nitrogen gas pressure measuring unit (**104**) for measuring the pressure of the low-pressure nitrogen gas downstream from a point midway in the heat exchanger (**1**) in the low-pressure nitrogen line (L**11**), and a low-pressure nitrogen control unit (**24**) that controls a low-pressure nitrogen control valve (V**12**) disposed in the low-pressure nitrogen line (L**11**) based on the pressure measured by the low-pressure nitrogen gas pressure measurement unit (**104**) (for example, when within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value).

**[0039]** The oxygen liquefaction apparatus (A**4**) may comprise:

**[0040]** a nitrogen liquefier (E**2**) for liquefying nitrogen gas (MP GAN) discharged from the hot end of the heat exchanger (**1**) as well as nitrogen gas (Feed $N_2$) sent from a supply source,

**[0041]** a feed nitrogen compressor (C**2**) for compressing the nitrogen gas (MP GAN) discharged from the hot end of the heat exchanger (**1**) as well as the nitrogen gas (Feed $N_2$) from the supply source,

**[0042]** at least a serially connected first-stage first booster (**51**) (that compresses the nitrogen gas compressed by the feed nitrogen compressor (C**2**)) and second booster (**61**) (that further boosts the pressure of a portion of the nitrogen gas that has been pressure-boosted by the first stage first booster (**51**)),

**[0043]** a first expansion turbine (**52**) by which the remainder (other than the portion noted above) of the nitrogen gas pressure-boosted by the first-stage first booster (**51**) is introduced into the hot end of the nitrogen liquefier (E**2**), and nitrogen gas discharged from a point midway therein is expanded,

**[0044]** a second expansion turbine (**62**) by which the nitrogen gas that has been pressure-boosted by the second-stage second booster (**61**) is introduced into the hot end of the nitrogen liquefier (E**2**), and a portion of the nitrogen gas discharged from a point midway therein (via a line L**13***a*) is expanded,

**[0045]** a first expansion valve (V**13**) by which the nitrogen gas that has been pressure-boosted by the second-stage second booster (**61**) is introduced into the hot end of the nitrogen liquefier (E**2**), and the remainder (other than the portion noted above) of nitrogen gas discharged from the cold end (via a line L**13**) is expanded,

**[0046]** a gas-liquid separator (**7**) into which the first nitrogen gas-liquid mixture expanded by the first expansion valve (V**13**) is introduced for the separation of the gas and liquid,

**[0047]** a second heat exchanger (E**3**) by which a portion of the liquefied nitrogen (MP LIN) separated in the gas-liquid separator (**7**) is cooled by being introduced into the hot end and discharged from the cold end,.

**[0048]** a low-pressure nitrogen discharge line (L**11***a*) through which the liquefied nitrogen (LP LIN) cooled by the second heat exchanger (E**3**) is discharged, a portion of which is sent to the low-pressure liquefied nitrogen line (L**11**),

**[0049]** a second expansion valve (V**14**) that branches off from the low-pressure nitrogen discharge line (L**11***a*) and that expands the remainder of the low-pressure liquefied nitrogen (the remainder other than the portion noted above),

**[0050]** a first recycled nitrogen line (L**12**) through which the second nitrogen gas-liquid mixture expanded by the second expansion valve (V**14**) is introduced into the cold end and discharged from the hot end of the second heat exchanger (E**3**), merged in the low-pressure nitrogen line (L**11**), and then introduced into the cold end and discharged from the hot end of the nitrogen liquefier (E**2**),

**[0051]** a first recycled nitrogen compressor (C**1**) that is disposed downstream from the hot end of the nitrogen liquefier (E**2**) in the first recycled nitrogen line (L**12**) and that compresses the recycled low-pressure nitrogen, and

**[0052]** a second recycled nitrogen line (L**13***b*) through which the intermediate-pressure nitrogen gas separated in the gas-liquid separator (**7**) is introduced into the cold end and discharged from the hot end of the nitrogen liquefier (E**2**), and is merged between the recycled nitrogen compressor (C**1**) and the feed nitrogen compressor (C**2**) of the first recycled nitrogen line (L**12**).

**[0053]** The nitrogen gas discharged from the first expansion turbine (**52**) (via line L**12**) may be introduced at a point midway in the nitrogen liquefier (E**2**) and merged in the second recycled nitrogen line (L**13***b*) in the nitrogen liquefier (E**2**).

**[0054]** The nitrogen gas discharged from the second expansion turbine (**62**) (via line L**13***a*) may be merged in the second recycled nitrogen line (L**13***b*) upstream from the cold end of the nitrogen liquefier (E**2**).

**[0055]** The liquefaction apparatus of the present disclosure can effectively liquefy by-product oxygen gas and argon gas supplied from air separation units, nitrogen liquefiers, oxygen generators, and water electrolysis units.

**[0056]** Examples of gases that can be liquefied by the liquefaction apparatus of the present disclosure include, but are not limited to, oxygen and argon.

**[0057]** The refrigerant for the liquefaction treatment in the liquefaction apparatus of the present disclosure may be, for example, liquefied nitrogen or liquefied natural gas.

## Effects

**[0058]** The present disclosure allows liquid products of suitable temperature (liquefied oxygen and liquefied argon) to be efficiently produced.

**[0059]** Preventing unnecessary increases and decreases in pressure in liquefied product storage tanks will prevent thermal energy or molecules of the liquefied product from being wasted, such as when the contents are released as a result of drops in pressure in storage tanks or when liquefied product is evaporated off for re-pressurization, and will therefore greatly help to improve the efficiency of the liquefied product supply chain.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0060]** Other features and advantages of the invention will be further disclosed in the description that follows, and in several embodiments provided as non-limiting examples in reference to the appended schematic drawings, in which:

**[0061]** FIG. **1** is a diagram illustrating a gas liquefaction apparatus according to Embodiment 1,

**[0062]** FIG. **2** is a diagram illustrating a gas liquefaction apparatus according to Embodiment 2,

**[0063]** FIG. **3** is a diagram illustrating a gas liquefaction apparatus according to Embodiment 3, and

**[0064]** FIG. **4** is a diagram illustrating a gas liquefaction apparatus according to Embodiment 4.

## DETAILED DESCRIPTION OF THE INVENTION

**[0065]** Several embodiments of the present invention will be described below. The embodiments described below are given as examples of the present disclosure. The present disclosure is in no way limited by the following embodiments, and also includes a number of variants that can be implemented within a scope that does not alter the gist of the present disclosure. It should be noted that not all the configurations described below are necessarily essential to the present disclosure. Upstream and downstream are based on the direction in which the fluid flows.

### Embodiment 1

**[0066]** A liquefaction apparatus A**1** according to Embodiment 1 will be described with the aid of FIG. **1**.

**[0067]** The oxygen liquefaction apparatus A**1** comprises a single heat exchanger **1**. In the oxygen liquefaction apparatus A**1**, oxygen gas (GOX) flows down into the hot end, and liquefied oxygen (LOX) is discharged from the cold end. Liquefied nitrogen (LIN) also flows upward via the cold end, and nitrogen gas (GAN) is discharged from the hot end. The nitrogen line L**1** is a nitrogen flow path for introducing liquefied nitrogen (LIN) through the cold end and discharging nitrogen gas (GAN) from the hot end of the heat exchanger **1**. The oxygen line L**2** is an oxygen line for introducing oxygen gas (GOX) from the hot end and discharging liquefied oxygen (LOX) from the cold end of the heat exchanger **1**.

**[0068]** A gate valve V**1** is disposed upstream from the cold end of the heat exchanger **1** in the nitrogen line L**1**.

**[0069]** A nitrogen gas pressure measurement unit **101** measures the pressure of the nitrogen gas downstream from the cold end of the heat exchanger **1** in the nitrogen line L**1**.

**[0070]** A nitrogen control unit **21** controls the opening and closing (adjusts the opening) of a nitrogen control valve V**2** disposed in the nitrogen line L**1** when, for example, within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value, based on the pressure value measured by the nitrogen gas pressure measurement unit **101**.

**[0071]** A gate valve V**3** is disposed upstream from the hot end of the heat exchanger **1** in the oxygen line L**2**.

**[0072]** An oxygen differential pressure measurement unit **102** measures the difference in pressure between the pressure of oxygen gas upstream from the hot end of the heat exchanger **1** in the oxygen line L**2** and the pressure of liquefied oxygen downstream from the cold end of the heat exchanger **1** in the oxygen line L**2**.

**[0073]** An oxygen control unit **22** controls the opening and closing (adjusts the opening) of an oxygen control valve V**4** disposed in the oxygen line L**2** when, for example, within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value, based on the pressure value measured by the oxygen gas pressure measurement unit **102**.

**[0074]** The oxygen control unit **22** calculates the level of liquefied oxygen inside the heat exchanger **1** based on the difference in pressure measured by the oxygen differential pressure measurement unit **102**, controls the oxygen control valve V**4** to adjust the liquid level, and controls the heat transfer area to control condensation of the oxygen.

**[0075]** The liquefied oxygen in the heat exchanger **1** is subcooled by heat exchange with the liquefied nitrogen. When attempting to control the temperature of the liquefied nitrogen in cases where the liquefied oxygen is under-or over-cooled, the nitrogen pressure must be adjusted, but energy will be needed to compress and decompress the nitrogen. The level of the oxygen is therefore adjusted to adjust the heat transfer area involved in subcooling the liquefied oxygen. This allows the liquefied oxygen temperature to be adjusted without changing the nitrogen operating pressure. The nitrogen line L**1** pressure control (**101**, **21**) is configured so that the nitrogen that is evaporated via heat exchange with oxygen is discharged through the piping and out of the system.

### Embodiment 2

**[0076]** An oxygen liquefaction apparatus A**2** according to Embodiment 2 will be described with the aid of FIG. **2**. The oxygen liquefaction apparatus A**2** according to Embodiment 2 has the functions of the oxygen liquefaction apparatus A**1** according to Embodiment 1, and additional functions are described below. Reference symbols which are the same denote the same functions.

**[0077]** A liquefied oxygen bypass line L**21** is a line by which a portion of the hot liquefied oxygen is discharged from a point midway in the heat exchanger **1** and is merged with liquefied product downstream from the cold end of the heat exchanger **1** of the oxygen line L**2** so as to adjust the temperature of the liquefied oxygen taken out as the final product.

**[0078]** A liquefied oxygen temperature measurement unit **103** measures the temperature of the liquefied oxygen downstream from the cold end of the heat exchanger **1** in the oxygen line L**2**.

**[0079]** A hot oxygen control unit **23** controls the opening and closing (adjusts the opening) of a hot oxygen control valve V**5** disposed in the liquefied oxygen bypass line L**21** when, for example, within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value, based on the temperature value measured by the liquefied oxygen temperature measurement unit **103**. This allows the temperature of the liquefied oxygen product to be controlled to a specified value, thereby allowing liquefied oxygen having a stable temperature to be produced at a low cost.

**[0080]** With this configuration, hot liquefied oxygen is discharged from a point midway in the flow path of the oxygen line L**2** of the heat exchanger **1** and is mixed with liquefied oxygen discharged from the cold end of the heat exchanger **1** to thereby produce the liquefied oxygen product. This allows liquefied oxygen of a suitable temperature to be supplied on demand. The subcooling temperature is preferably approximately at least 1° C. lower than the temperature of the saturated liquid at operating pressure in order to prevent the discharged hot liquid oxygen from flowing in two layers as a result of partial evaporation due to reduced pressure or heat coming from the environment. This is because partial evaporation due to loss of pressure may result in a two-layered flow.

## Embodiment 3

**[0081]** An oxygen liquefaction apparatus A**3** according to Embodiment 3 will be described with the aid of FIG. **3**. The oxygen liquefaction apparatus A**3** according to Embodiment 3 has the functions of the oxygen liquefaction apparatus A**1** and A**2** according to Embodiments 1 and 2, and additional functions are described below. Reference symbols which are the same denote the same functions.

**[0082]** Intermediate-pressure liquefied nitrogen (MP LIN) is supplied to the nitrogen line L**1**.

**[0083]** A low-pressure nitrogen line L**11** is a line for introducing low-pressure liquefied nitrogen (LP LIN) through the cold end of the heat exchanger **1** and discharging low-pressure nitrogen gas (LP GAN) from the a point midway in the heat exchanger **1**.

**[0084]** A low-pressure nitrogen gas pressure measurement unit **104** measures the pressure of low-pressure nitrogen gas downstream from a point midway in the heat exchanger **1** in the nitrogen line L**11**.

**[0085]** A low-pressure nitrogen control unit **24** controls the opening and closing (adjusts the opening) of a low-pressure nitrogen control valve V**12** disposed in the low-pressure nitrogen line L**11** when, for example, within a predetermined range, or below a predetermined threshold value, or at or over the predetermined threshold value, based on the pressure measured by the low-pressure nitrogen gas pressure measurement unit **104**.

**[0086]** This will allow liquefied nitrogen to be used to cool and liquefy oxygen gas, and will allow low-pressure liquefied nitrogen to be used in the subcooling of liquefied oxygen.

**[0087]** With this configuration, liquefied oxygen is subcooled by low-temperature liquefied nitrogen. The intermediate-pressure liquefied nitrogen can be optimized for cooling and liquefying oxygen gas, and the low-temperature liquefied nitrogen can be used to optimize the subcooling of liquefied oxygen, resulting in more efficient heat exchange.

## Embodiment 4

**[0088]** An oxygen liquefaction apparatus A**4** according to Embodiment 4 will be described with the aid of FIG. **4**. The oxygen liquefaction apparatus A**4** according to Embodiment 4 has the functions of the oxygen liquefaction apparatus A**1**, A**2**, and A**3** according to Embodiments 1, 2, and 3, and additional functions are described below. Reference symbols which are the same denote the same functions.

**[0089]** The oxygen liquefaction apparatus A**4** comprises a nitrogen liquefier E**2** for liquefying nitrogen gas (Feed $N_2$) sent from a supply source via a line L**4**. The nitrogen liquefier E**2** is composed of a heat exchanger, for example.

**[0090]** A recycled nitrogen compressor C**1** and feed nitrogen compressor C**2** are connected in series via a line L**12**. The first recycled nitrogen compressor C**1** is disposed downstream from the hot end of the nitrogen liquefier E**2** in the first recycled nitrogen line L**12**, and compresses the recycled low-pressure nitrogen. The feed nitrogen compressor C**2** compresses nitrogen gas (MP GAN) discharged from the hot end of the heat exchanger **1** and nitrogen gas (Feed $N_2$) from a supply source. The feed nitrogen compressor C**2** compresses the nitrogen gas compressed by the recycled nitrogen compressor C**1**. The feed nitrogen compressor C**2** also compresses nitrogen gas that has been expanded by the first expansion turbine **52** described below and introduced into the nitrogen liquefier E**2**. The feed nitrogen compressor C**2** also compresses nitrogen gas that has been separated in the gas-liquid separator **7** described below and introduced into the nitrogen liquefier E**2**.

**[0091]** A first booster **51** and the second booster **61** are connected in series via the line L**12** and a line L**13**.

**[0092]** The first booster **51** boosts the pressure of the nitrogen gas that has been compressed by the feed nitrogen compressor C**2**. The second booster **61** further boosts the pressure of a portion of the nitrogen gas pressure-boosted by the first booster **51**.

**[0093]** A first expansion turbine **52** is provided, whereby the remainder of the nitrogen gas (remainder of the portion of nitrogen gas sent to the second booster **61**) that has been pressure-boosted by the first-stage first booster **51** is introduced via the first recycled nitrogen line L**12** into the hot end of the nitrogen liquefier E**2**, and nitrogen gas discharged from a point midway therein is expanded. The expanded nitrogen gas is introduced via the first recycled nitrogen line L**12** into a point midway in the nitrogen liquefier E**2** and is merged in a second recycled nitrogen line L**13***b*.

**[0094]** A second expansion turbine **62** is provided, by which the nitrogen gas that has been pressure-boosted by the second booster **61** is introduced into the hot end of the nitrogen liquefier E**2**, and a portion of the nitrogen gas discharged from a point midway in the nitrogen liquefier E**2** is expanded via a line L**13***a*. The expanded nitrogen gas merges, via the line **13***a*, in a second recycled nitrogen line L**13***b* by which separated nitrogen gas is introduced from the gas-liquid separator **7** into the cold end of the nitrogen liquefier E**2**.

**[0095]** A first expansion valve V**13** is disposed in the line L**13** downstream from the cold end of the nitrogen liquefier E**2**. The first expansion valve V**13** introduces nitrogen gas that has been pressure-boosted by the second booster **61** into the hot end of the nitrogen liquefier E**2** and expands the remainder of the nitrogen gas discharged from the cold end (the remainder of the portion of nitrogen gas sent to the second expansion turbine **62**).

**[0096]** The first nitrogen gas-liquid mixture expanded by the first expansion valve V**13** is introduced into a gas-liquid separator **7** where the gas and liquid are separated. The separated nitrogen gas is introduced via the first recycled nitrogen line L**13***b* into the cold end and discharged from the hot end of the nitrogen liquefier E**2** and is merged in the second recycled nitrogen line L**12**. A portion of the separated liquefied nitrogen is introduced as thermal energy via the liquefied nitrogen line L**1** into the heat exchanger **1**, and the remainder is introduced into a second heat exchanger E**3** described below.

**[0097]** The second heat exchanger E**3** is such that the remainder of the liquefied nitrogen (MP LIN) separated in the gas-liquid separator **7** (the remainder of the portion of liquefied nitrogen introduced into the heat exchanger **1**) is cooled by being introduced into the hot end and discharged from the cold end. A portion of the liquefied nitrogen (LP LIN) that has been cooled in the second heat exchanger E**3** is introduced as subcooling thermal energy via the low-pressure liquefied nitrogen line L**11** into the heat exchanger **1**.

**[0098]** A second expansion valve V**14** is disposed in the first recycled nitrogen line L**12** branching off from the low-pressure nitrogen discharge line L**11***a*, and expands the remainder of the low-pressure liquefied nitrogen (the remainder of the portion introduced into the heat exchanger **1**).

**[0099]** The low-pressure nitrogen discharge line L**11***a* is a line for discharging liquefied nitrogen (LP LIN) cooled in the second heat exchanger E**3** and sending a portion thereof to the low-pressure liquefied nitrogen line L**11**.

**[0100]** The first recycled nitrogen line L**12** is a line through which the second nitrogen gas-liquid mixture expanded by the second expansion valve V**14** is introduced into the cold end and discharged from the hot end of the second heat exchanger E**3**, merged in the low-pressure nitrogen line L**11**, and then introduced into the cold end and discharged from the hot end of the nitrogen liquefier E**2**.

**[0101]** The second recycled nitrogen line L**13***b* is a line through which the intermediate-pressure nitrogen gas separated in the gas-liquid separator **7** is introduced into the cold end and discharged from the hot end of the nitrogen liquefier E**2**, and is merged between the recycled nitrogen compressor C**1** and the feed nitrogen compressor C**2** of the first recycled nitrogen line L**12**.

**[0102]** With this configuration, intermediate-pressure liquefied nitrogen and low-pressure, low-temperature liquefied nitrogen are each supplied from a nitrogen liquefaction cycle, and the gasified products are each returned to the liquefied nitrogen cycle. The nitrogen gas discharged from the heat exchanger **1** can thus be recovered efficiently in terms of heat and mass balance.

**[0103]** In the above embodiments, argon can be liquefied instead of oxygen as the liquefied product or liquefied gas.

## EXAMPLE

**[0104]** A simulation was performed with the configuration of Embodiment 3 (FIG. **3**).

**[0105]** Oxygen gas was introduced through the hot end of a heat exchanger **1** at 21° C., 6.8 barA, and 6500 Nm$^3$/h, and was discharged in the form of liquefied oxygen from the cold end at −184° C. As the boiling point of oxygen at 6.8 barA is approximately −160° C., intermediate-pressure liquefied nitrogen that would result in subcooling at 24° C. was introduced at −180° C., 4.81 barA, and 7079 Nm3/h, and was discharged in the form of intermediate-pressure nitrogen gas at 9.1° C.

**[0106]** Low-pressure liquefied nitrogen was introduced at −192° C., 3.26 barA, 1622 Nm$^3$/h, and was discharged in the form of low-pressure nitrogen gas at −185° C.

**[0107]** When the temperature of low-pressure liquefied nitrogen falls at reduced pressure, for example, there is a corresponding decrease in the temperature of liquefied oxygen. A fall in the liquid oxygen temperature to below the set value of 2° C. would result in subcooling at 26° C. and thus approximately 8.3% over-cooling.

**[0108]** In one example, the heat exchanger 1 has a 4000-mm high first section (cooling/condensing area **1***a*) for cooling and condensing oxygen gas, and a 900-mm second section (subcooling area **1***b*) for subcooling liquefied oxygen, where the level of the liquefied oxygen in the heat exchanger **1** is, by design, at the boundary between the first and second sections. In the event of 8.3% over-cooling, the level of the liquefied oxygen is controlled to 900 mm×(100%−8.3%)=825 mm. As the specific gravity of liquefied oxygen is 1.11, valve **4** on the liquefied oxygen product discharge line L**2** is controlled so as to result in a measured differential pressure of between 100 mbar and 92 mbar.

**[0109]** To furthermore prevent an over-cooled liquefied oxygen product from being supplied during the above level-controlling procedure, hot liquefied oxygen having a temperature of −176° C. can be discharged at 1300 Nm$^3$/h from the hot liquefied oxygen bypass line L**21** as cold liquefied oxygen having a temperature of −186° C. is discharged at 5200 Nm$^3$/h, and they can be mixed in order to produce liquefied oxygen at 6,500 Nm$^3$/h, thereby producing a liquefied oxygen product having a temperature of −184° C. Liquefied oxygen of stable temperature and quality can thus be produced while reducing the thermal energy consumption of the liquefied nitrogen refrigerant corresponding to the 8.3% over-cooling noted above.

**[0110]** (Other embodiments) (1) Although not explicitly stated, pressure regulating devices and flow rate control devices, etc. may be installed in each pipeline in order to regulate pressure and regulate flow rate.

**[0111]** (2) Although not explicitly stated, control valves and gate valves, etc. may be installed in each line.

**[0112]** (3) A nitrogen differential pressure measurement unit may be provided instead of the oxygen differential pressure measurement unit **102**, the level of the nitrogen may be calculated based on the differential pressure value, the oxygen control valve V**4** may be controlled to adjust the level, and the heat transfer area may be controlled to control the condensation of oxygen.

**[0113]** While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications, and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications, and variations as fall within the spirit and broad scope of the appended claims. The present invention may suitably comprise, consist or consist essentially of the elements disclosed and may be practiced in the absence of an element not disclosed. Furthermore, if there is language referring to order, such as first and second, it should be understood in an exemplary sense and not in a limiting sense. For example, it can be recognized by those skilled in the art that certain steps can be combined into a single step.

**[0114]** The singular forms "a", "an" and "the" include plural referents, unless the context clearly dictates otherwise.

**[0115]** "Comprising" in a claim is an open transitional term which means the subsequently identified claim elements are a nonexclusive listing (i.e., anything else may be additionally included and remain within the scope of "comprising"). "Comprising" as used herein may be replaced by the more limited transitional terms "consisting essentially of" and "consisting of" unless otherwise indicated herein.

**[0116]** "Providing" in a claim is defined to mean furnishing, supplying, making available, or preparing something. The step may be performed by any actor in the absence of express language in the claim to the contrary.

**[0117]** Optional or optionally means that the subsequently described event or circumstances may or may not occur. The description includes instances where the event or circumstance occurs and instances where it does not occur.

**[0118]** Ranges may be expressed herein as from about one particular value, and/or to about another particular value. When such a range is expressed, it is to be understood that another embodiment is from the one particular value and/or to the other particular value, along with all combinations within said range.

## KEY TO SYMBOLS

**[0119]** **1** Heat exchanger

**[0120]** **22** Oxygen control unit

**[0121]** **23** Hot liquefied oxygen control unit

**[0122]** **102** Oxygen differential pressure measurement unit

**[0123]** **103** Liquefied oxygen temperature measurement unit

**[0124]** A**1**, A**2**, A**3**, A**4** Oxygen liquefaction apparatus

**[0125]** V**4** Oxygen control valve

**[0126]** V**5** Hot oxygen control valve

**1**. A liquefaction apparatus comprising:

a heat exchanger configured to cool and condense a gas using a refrigerant to form a liquefied product, wherein the gas flows through a first path of the heat exchanger, the first path having a cold end and a hot end, wherein the refrigerant flows through a refrigerant flow path having a cold end and a hot end;

a first differential pressure gauge configured to measure a difference in pressure between the hot end and the cold end; and

a liquefied product control unit configured to calculate a level of the liquefied product inside the heat exchanger based on the differential pressure gauge reading,

wherein the liquefied product control unit is further configured to control a liquefied product control valve to adjust the level of the liquefied product, and

wherein the liquefied product control unit is further configured to control the heat transfer area to control the condensation of the gas.

**2**. The liquefaction apparatus according to claim **1**, further comprising a second differential pressure gauge configured to measure a difference in pressure between the hot end and the cold end of the refrigerant flow path, wherein the liquefied product control unit is configured to calculate a level of the refrigerant, to control the liquefied product control valve to adjust the level of the refrigerant, and to control the heat transfer area, which allows the liquefied product control unit to control the condensation of the substance that is to be treated.

**3**. The liquefaction apparatus according to claim **1**, further comprising a second differential pressure gauge configured to measure a difference in pressure between the hot end and the cold end of the refrigerant flow path, wherein the liquefied product control unit is configured to control the liquefied product control valve based on the level of the refrigerant and the level of the liquefied product of the gas to adjust the levels of the refrigerant and the liquefied product, and to control the heat transfer area to control the condensation of the gas.

**4**. The liquefaction apparatus according to claim **1**, comprising:

a liquefied product discharge line through which the liquefied product is discharged from the cold end of the heat exchanger, and

a liquefied product bypass line that is configured to discharge the liquefied product from a part of the liquefied product flow path inside the heat exchanger that is lower than the level of the liquefied product and that merges with the liquefied product discharge line through which the product is discharged from the cold end of the heat exchanger.

**5**. The liquefaction apparatus according to claim **4**, comprising a bypass control unit that controls the opening and closing of a bypass control valve disposed on the liquefied product bypass line so that the temperature of the liquefied product is at a specified value.

**6**. A liquefied product production method comprising the steps of:

providing the liquefaction apparatus of claim **1**;

introducing the gas into the hot end of the first path of the heat exchanger;

introducing the refrigerant the cold end of the refrigerant path of the heat exchanger, wherein the gas is cooled and condensed within the first path of the heat exchanger by exchanging heat with the refrigerant flowing within the refrigerant path, thereby forming the liquefied product;

discharging the liquefied product from the cold end of the first path; and

controlling an amount of the liquefied product discharged from the cold end of the first path based on the level of liquefied product within the heat exchanger.

**7**. The liquefied product production method according to claim **6**, further comprising controlling the amount of the liquefied product discharged from the cold end of the first path based on the level of the refrigerant9098 within the heat exchanger.

**8**. The liquefied product production method according to claim **6**, further comprising adjusting a temperature within the heat exchanger by discharging a portion of the liquefied product from a part of the heat exchanger that is lower than the level of the liquefied product, and merging with liquefied product that is taken out as the final product, so as to adjust the temperature of the liquefied product.

**9**. The liquefied product production method according to claim **6**, further comprising subcooling the liquefied product using a combination of a primary refrigerant, that primarily effects cooling and condensation, as well as a second refrigerant, that has a lower pressure than the first refrigerant.

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