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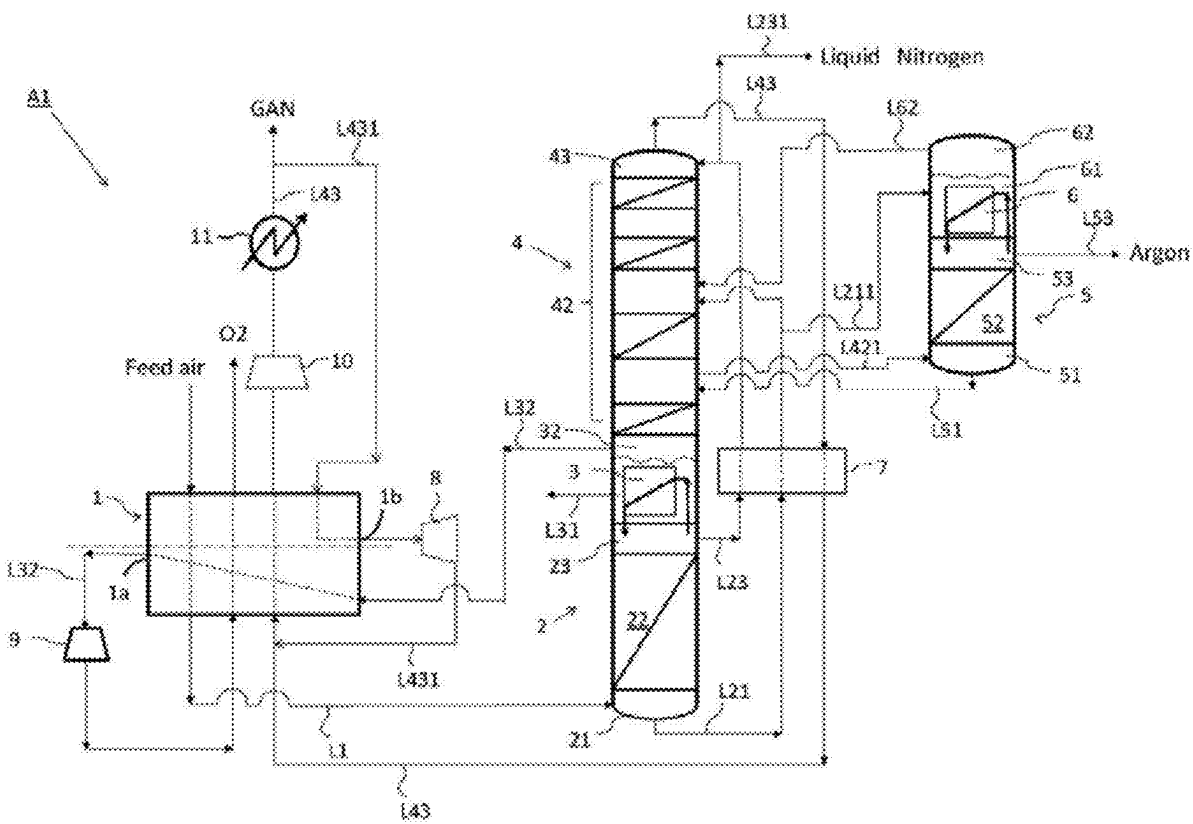
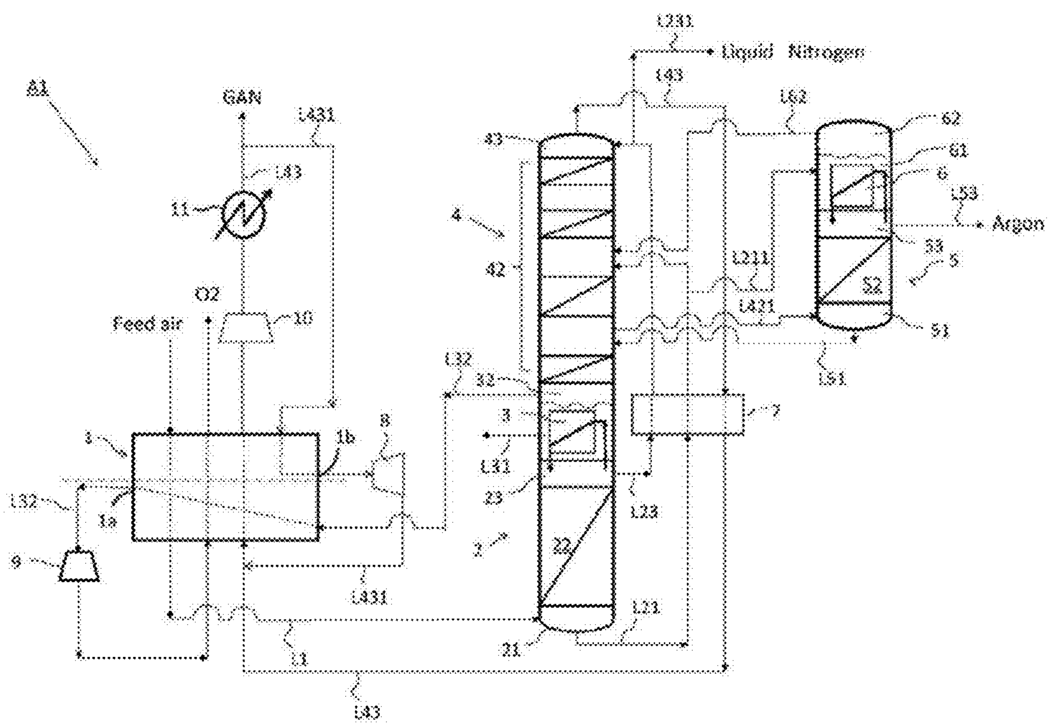
(57) **ABSTRACT**

An air separation unit including: a main heat exchanger, a medium-pressure rectification column, a low-pressure rectification column, a crude argon column, a nitrogen condenser, a crude argon condenser, an oxygen turbine, a nitrogen compressor, and a nitrogen turbine. The nitrogen turbine expands nitrogen gas supplied from the nitrogen compressor. The air separation unit includes an inlet temperature of the oxygen turbine is lower than an inlet temperature of the nitrogen turbine.



[Fig. 1]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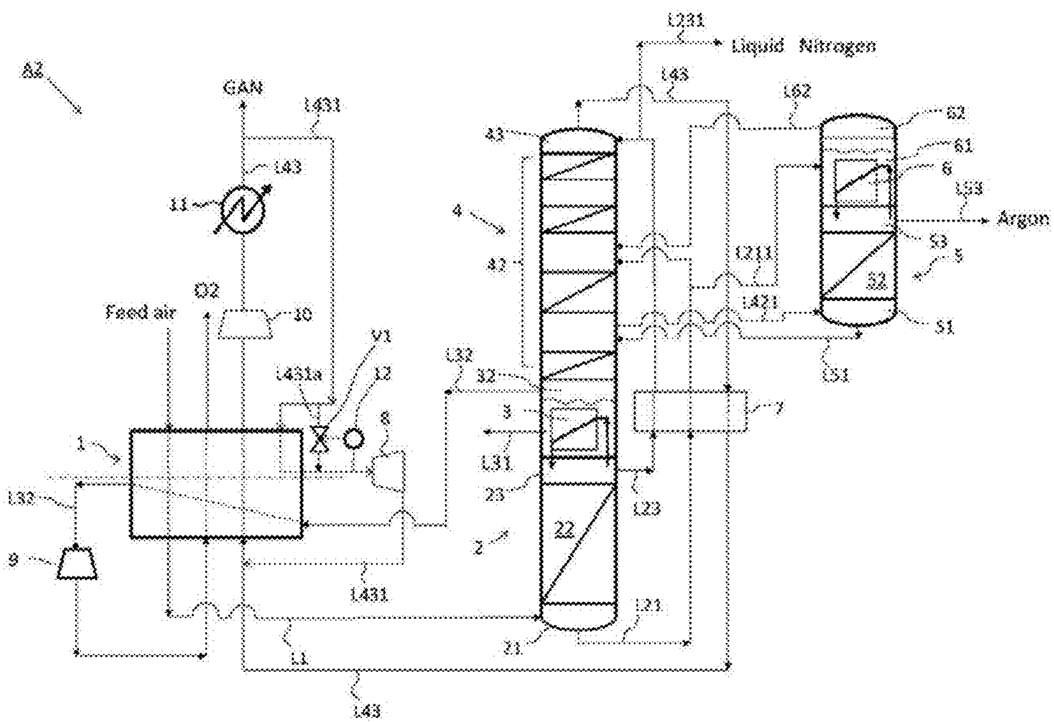
GAN
L431
L43
11
O2
Feed air
10
1
1b
8
1a
L32
9
L431
L1
L43
L231
Liquid Nitrogen
L43
L62
62
61
6
L53
Argon
43
4
42
53
5
L211
L421
52
51
L51
L32
32
3
L31
7
23
L23
2
22
L21
21

[Fig. 2]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V1
L431a
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8
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L431
L1
L43
L231
Liquid Nitrogen
L43
L62
62
61
6
L63
Argon
4
43
42
L211
53
5
52
L421
51
L51
L32
32
3
7
L31
23
L23
2
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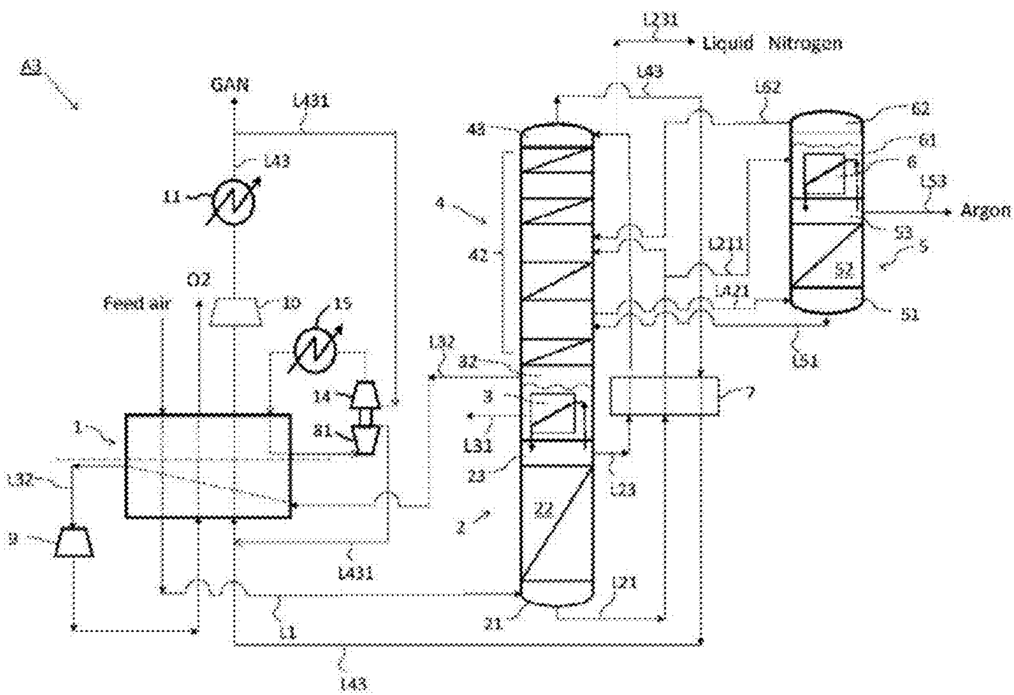
L21
21

[Fig. 3]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L431
L43
11
O2
Feed air
10
15
14
81
1
L32
9
L431
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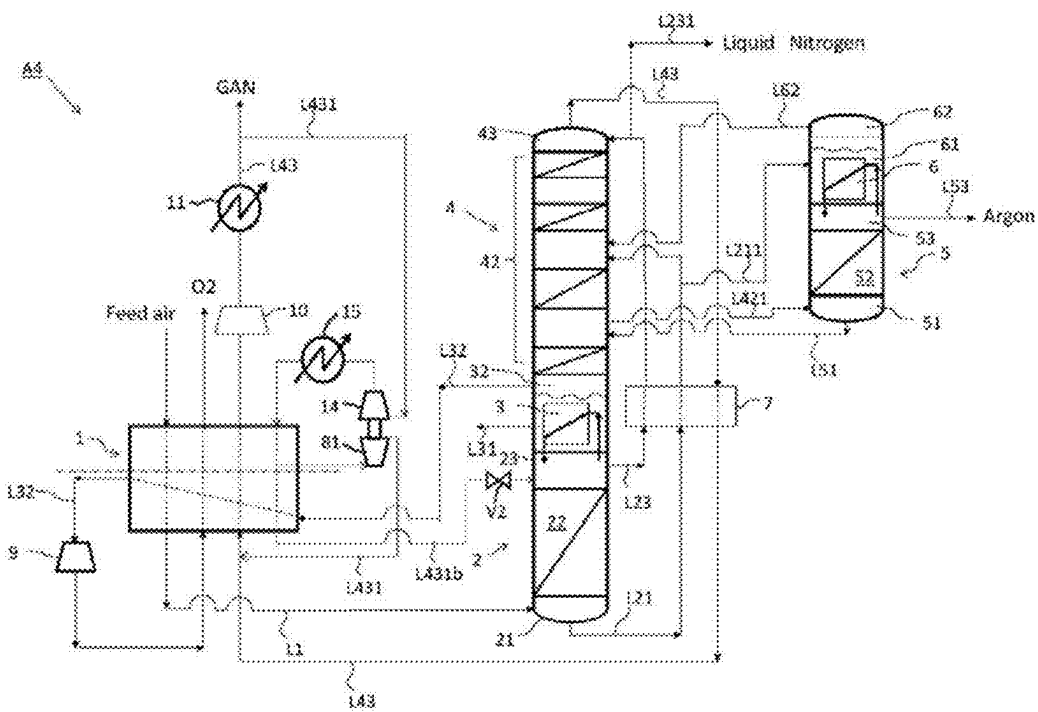
L43
L231
Liquid Nitrogen
L43
L62
62
61
6
L53
Argon
43
4
42
L211
L421
53
52
5
51
L51
L32
32
3
L31
23
L23
7
22
2
21
L21

[Fig. 4]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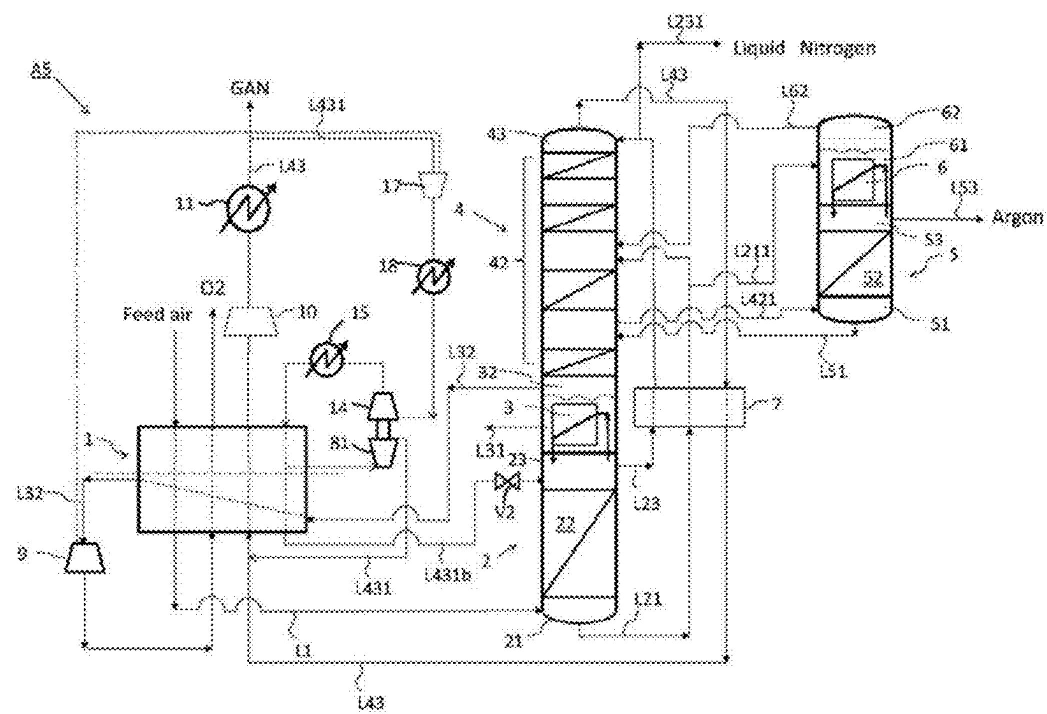
GAN
L431
L43
11
O2
Feed air
10
15
L32
32
3
14
81
1
L32
9
L31
23
V2
22
2
L431
L431b
L1
21
L43
L21
L23
7
43
4
42
L231
Liquid Nitrogen
L43
L62
62
61
6
L53
Argon
53
L211
52
5
L421
51
L51

[Fig. 5]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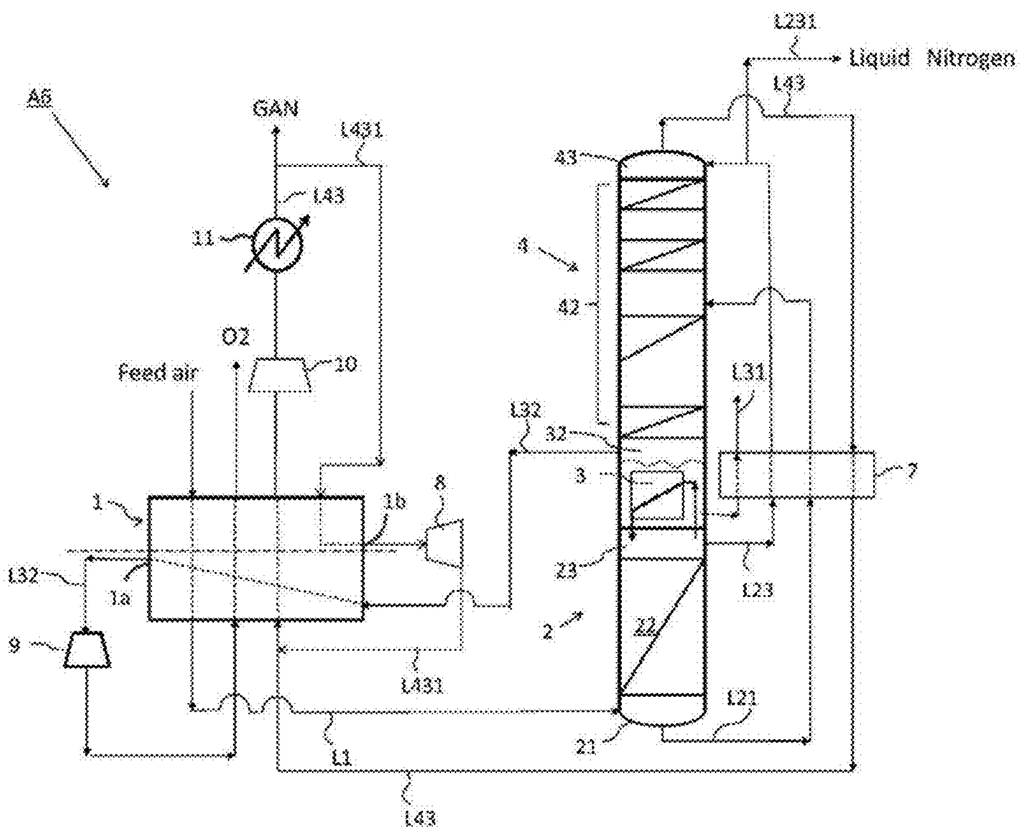
Liquid Nitrogen
A5
GAN
L431
L83
L62
62
61
6
L53
Argon
43
L43
11
17
4
42
16
O2
Feed air
10
15
L32
32
3
14
81
1
L31
23
L32
V2
22
9
L431
L431b
2
L23
L211
53
5
52
L421
51
L51
7
21
L21
L1
L1
L43

[Fig. 6]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L43
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GAN
L431
43
L43
11
4
42
O2
10
Feed air
L31
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3
7
1
1b
8
L32
1a
23
L23
2
22
9
L431
L21
L1
21
L43

AIR SEPARATION UNIT

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. JP 2024-022972, filed Feb. 19, 2024, the entire contents of which are incorporated herein by reference.

BACKGROUND

[0002] The present invention relates to an air separation unit. The present invention relates to a cryogenic air separation unit capable of separating nitrogen and rare gases such as argon.

Field of the Invention

[0003] Multi-column rectification systems comprising a plurality of rectification columns such as a medium-pressure column, a low-pressure column, and a crude-argon column, are used when air components are separated into nitrogen, argon and oxygen, etc. by means of cryogenic air separation. When power for gas compression is minimized for optimum supply while simultaneously increasing the nitrogen and argon recovery rates in particular, an inlet pressure of a nitrogen compressor for compressing low-pressure nitrogen gas drawn from the low-pressure rectification column is raised by increasing the pressure of the low-pressure nitrogen gas, which reduces the load on the nitrogen compressor. The pressure in the low-pressure rectification column is increased at this time, so the cold needed to maintain the heat balance in the air separation unit can be generated by means of an expansion turbine which expands oxygen gas drawn from the bottom of the low-pressure rectification column (e.g., Patent Documents 1 and 2).

Related Art

[0004] The product gas produced from the air separation unit needs to be supplied as a liquid for storage and transportation. Known methods for generating the cold for gas liquefaction include a method for expanding a portion of the feed air (e.g., Patent Document 3), and a method for recycling and expanding the nitrogen gas drawn from the medium-pressure column (e.g., Patent Document 4). However, in order to vaporize liquid oxygen collected in the bottom of the low-pressure column, these methods employ a portion of the medium-pressure air introduced into the medium- pressure rectification column or a portion of the medium-pressure nitrogen collected at the top of the medium-pressure rectification column, which therefore leads to the problem of a reduced vapour stream inside the rectification column and a drop in nitrogen or argon recovery.

PRIOR ART DOCUMENTS

Patent Documents

[0005] [Patent Document 1] U.S. Pat. No. 20,192,93347 A1

[0006] [Patent Document 2] U.S. Pat. No. 20,233,58468 A1

[0007] [Patent Document 3] WO 2021/230911 A1

[0008] [Patent Document 4] JP S63-187086 A

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

[0009] The present disclosure provides an air separation unit which generates cold by expanding oxygen gas separated from air, wherein a heat balance can be maintained without a drop in rare gas and nitrogen recovery rates, by using a nitrogen turbine to supply cold needed for the production of product oxygen or for the production of a liquid product such as liquid nitrogen or liquid argon.

Means for Solving the Problems

[0010] An air separation unit according to the present disclosure comprises: a main heat exchanger (**1**), a medium-pressure rectification column (**2**), a low-pressure rectification column (**4**), a crude argon column (**5**), a nitrogen condenser (**3**), a crude argon condenser (**6**), an oxygen turbine (**9**), a nitrogen compressor (**10**), and a nitrogen turbine (**8**).

[0011] The nitrogen turbine (**8**) expands nitrogen gas supplied from the nitrogen compressor (**10**). The air separation unit is characterized in that an inlet temperature of the oxygen turbine (**9**) is lower than an inlet temperature of the nitrogen turbine (**8**). For example, the temperature of a gas drawn from a first intermediate portion (**1***a*) of the main heat exchanger (**1**) and delivered to the oxygen turbine (**9**) is lower than the temperature of a gas drawn from a second intermediate portion (**1***b*) of the main heat exchanger (**1**) and delivered to the nitrogen turbine (**8**). A position (**1***a*) of an extraction nozzle of a pipe connected to the oxygen turbine (**9**) from the main heat exchanger (**1**) may be disposed on the low temperature side of a position (**1***b*) of an extraction nozzle of a pipe connected to the nitrogen turbine (**8**). Furthermore, a bypass pipe (L**431***a*) may be provided from the nitrogen gas pipe at the warm end of the main heat exchanger (**1**) to the nitrogen turbine inlet pipe so that the inlet temperature of the nitrogen turbine (**8**) is higher than the inlet temperature of the oxygen turbine (**9**).

[0012] The air separation unit may comprise a first nitrogen booster (**14**), and the first nitrogen booster (**14**) may be driven by means of an expansion turbine (**81**).

[0013] The air separation unit may comprise a second nitrogen booster (**17**), and the second nitrogen booster (**17**) may be driven by means of the oxygen turbine (**9**).

[0014] The air separation unit may be configured so that a portion of the compressed nitrogen gas supplied from the nitrogen compressor (**10**) is cooled in the main heat exchanger (**1**) and supplied to the medium-pressure rectification column (**2**).

[0015] The air separation unit may comprise a sub-cooler (**7**) (see FIG. **6**) for cooling a liquid (e.g., an oxygen-rich liquid), which is drawn from the medium-pressure rectification column (**2**), by means of a gas drawn from the low-pressure rectification column (**4**) or from the crude argon condenser (**6**).

[0016] Oxygen gas drawn from the low-pressure rectification column (**4**) or a gas phase in a refrigerant storage portion (**32**) of the nitrogen condenser (**3**) may be mixed with nitrogen gas drawn from the low-pressure rectification column (**4**) or oxygen-rich gas drawn from the crude argon condenser (**6**), and then expanded by the oxygen turbine (**9**). The main heat exchanger (**1**) may have a divided structure in order to optimize the structure according to design temperature, pressure and flow rate, and to improve ease of transportation.

[0017] The following actions are demonstrated by virtue of the configuration above. The oxygen turbine (**9**) constantly generates the cold required for producing a product gas, but the expansion ratio is a ratio of the pressure in the low-pressure rectification column (**4**) and a low pressure close to atmospheric pressure which is sufficient to release the expanded gas into the atmosphere via the main heat exchanger (**1**), so the expansion ratio is only two to five times at the most. Nevertheless, the inlet temperature of the oxygen turbine (**9**) is low because it is necessary to supply the low-temperature gas required by the air separation unit.

[0018] Meanwhile, low-pressure nitrogen gas (LP GAN) drawn from the main heat exchanger (**1**) is supplied via the nitrogen compressor (**10**), but since the outlet pressure thereof can be freely increased, this allows the expansion ratio to be increased.

[0019] That is to say, the configuration of the nitrogen compressor (**10**) and the nitrogen turbine (**8**) is suitable for supplying the large amount of cold needed to liquefy the product gas.

[0020] However, the product gas is liquefied for storage and transportation, so constant operation is not necessarily needed. For this reason, the air separation unit according to the present disclosure is configured so that the inlet temperature of the oxygen turbine (**9**) is lower than that of the nitrogen turbine (**8**), with the oxygen turbine (**9**) serving as a base load cold source, and the nitrogen turbine (**8**) serving as a variable cold source. It is thus possible to respond easily to product gas and liquid requirements by supplying the cold needed for steady gas production by means of the oxygen turbine (**9**), and operating the nitrogen turbine (**8**) when further cold is needed. The heat balance on the low-temperature side of the main heat exchanger (**1**) can be maintained by the lower temperature supplied by the oxygen turbine (**9**), the inlet temperature of the nitrogen turbine (**9**) can be increased, and cold can be supplied more efficiently.

[0021] Air separation units (A**1**, A**2**, A**3**, A**4**, A**5**, A**6**) according to the present disclosure may comprise:

[0022] a main heat exchanger (**1**) having feed air introduced from a warm end thereof and drawn from a cold end thereof;

[0023] a medium-pressure rectification column (**2**) which has the feed air drawn from the cold end of the main heat exchanger (**1**) introduced into a bottom (**21**) thereof;

[0024] a nitrogen condenser (**3**) into which a vapour stream is introduced from an upper portion (**23**) of the medium-pressure rectification column (**2**), the vapour stream being condensed and drawn out as a reflux liquid;

[0025] a low-pressure rectification column (**4**) which has an oxygen-rich liquid drawn from the bottom (**21**) of the medium-pressure rectification column (**2**) introduced into a rectification portion (**42**) thereof and/or which has a vapour stream drawn from the upper portion (**23**) of the medium-pressure rectification column (**2**) introduced into a top (**43**) thereof;

[0026] an oxygen turbine (**9**) for expanding and cooling an oxygen-rich gas drawn from a gas phase in a refrigerant storage portion (**32**) of the nitrogen condenser (**3**), after the oxygen-rich gas has undergone heat exchange in the main heat exchanger (**1**); and

[0027] a nitrogen turbine (**8**) for expanding nitrogen gas drawn from the top (**43**) of the low-pressure rectification column (**4**), after said nitrogen gas has undergone heat exchange at least in the main heat exchanger (**1**), been compressed to a predetermined pressure in the nitrogen compressor (**10**), cooled in a cooling unit (**11**), and once again cooled in the main heat exchanger (**1**).

[0028] The air separation units (A**1**, A**2**, A**3**, A**4**, A**5**) may comprise:

[0029] a crude argon column (**5**) which has an oxygen-containing fluid drawn from the rectification portion (**42**) of the low-pressure rectification column (**4**) introduced into a bottom (**51**) thereof;

[0030] a crude argon condenser (**6**) into which a vapour stream is introduced from an upper portion of the crude argon column (**5**), the vapour stream being condensed and drawn out as a reflux liquid; and

[0031] a sub-cooler (**7**) which has an oxygen-rich liquid drawn from the bottom (**21**) of the medium-pressure rectification column (**2**) introduced from a warm end thereof and drawn from a cold end thereof, and/or which has a vapour stream drawn from the upper portion (**23**) of the medium-pressure rectification column (**2**) introduced from a warm end thereof and drawn from a cold end thereof, and/or which has nitrogen gas drawn from the top (**43**) of the low-pressure rectification column (**4**) introduced from a cold end thereof and drawn from a warm end thereof.

[0032] The air separation units (A**1**, A**2**, A**3**, A**4**, A**5**, A**6**) may comprise:

[0033] a feed air line (L**1**) for introducing feed air into the medium-pressure rectification column (**2**) via the main heat exchanger (**1**);

[0034] an oxygen-rich liquid pipeline (L**21**) for introducing an oxygen-rich liquid drawn from the bottom (**21**) of the medium-pressure rectification column (**2**) into the rectification portion (**42**) of the low-pressure rectification column (**4**) via the sub-cooler (**7**);

[0035] an oxygen-rich liquid branch pipeline (L**211**) which branches from the oxygen-rich liquid pipeline (L**21**) downstream from the sub-cooler (**7**) and serves to introduce the oxygen-rich liquid into a refrigerant storage portion (**61**) of the crude argon condenser (**6**);

[0036] a liquid nitrogen pipeline (L**23**) for introducing liquid nitrogen drawn from the upper portion (**23**) of the medium-pressure rectification column (**2**) into the top (**43**) of the low-pressure rectification column (**4**) via the sub-cooler (**7**);

[0037] a liquid nitrogen branch pipeline (L**231**) which branches from the liquid nitrogen pipeline (L**23**) downstream from the sub-cooler (**7**) and draws out a portion of the liquid nitrogen;

[0038] a liquid oxygen extraction line (L**31**) for extracting, as liquid oxygen (LOX), a refrigerant (oxygen-rich liquid) in the refrigerant storage portion (**32**) of the nitrogen condenser (**3**);

[0039] an oxygen extraction line (L**32**) which draws oxygen from an upper gas phase in the refrigerant storage portion (**32**) of the nitrogen condenser (**3**), introduces the oxygen at an intermediate stage of the main-heat exchanger (**1**) where the oxygen is warmed and then drawn out and expanded by the oxygen turbine (**9**), the oxygen then being once again introduced from the cold end of the main heat exchanger (**1**) and drawn from the warm end thereof, and extracted as oxygen gas;

[0040] an oxygen-containing fluid pipeline (L**421**) for drawing an oxygen-containing fluid from the rectification portion (**42**) of the low-pressure rectification column (**4**) and introducing the oxygen-containing fluid into the bottom (**51**) of the crude argon column (**5**);

[0041] a nitrogen gas pipeline (L**43**) which draws nitrogen gas from the top (**43**) of the low-pressure rectification column (**4**) and extracts nitrogen gas (GAN) via the sub-cooler (**7**) and the main heat exchanger (**1**);

[0042] a nitrogen gas branch pipeline (L**431**) which branches from the nitrogen gas pipeline (L**43**) downstream from the main heat exchanger (**1**), once again introduces the nitrogen gas from the warm end of the main heat exchanger (**1**), draws out nitrogen gas from an intermediate portion, the nitrogen gas then being expanded by the nitrogen turbine (**8**) and merged into the nitrogen gas pipeline (L**43**) or extracted as nitrogen gas once again via the main heat exchanger (**1**);

[0043] a crude argon column-bottom fluid pipeline (L**51**) for drawing a bottom fluid from the bottom (**51**) of the crude argon column (**5**), and introducing the bottom fluid below a draw-out position of the oxygen-containing fluid pipeline (L**421**) in the rectification portion (**42**) of the low-pressure rectification column (**4**);

[0044] an argon extraction line (L**53**) for drawing a vapour stream or a reflux liquid from the upper portion of the crude argon column (**5**); and

[0045] a crude argon condenser pipeline (L**62**) for drawing an upper vapour phase in the refrigerant storage portion (**62**) of the crude argon condenser (**6**), and introducing same into the rectification portion (**42**) of the low-pressure rectification column (**4**) above the oxygen-rich liquid pipeline (L**21**).

[0046] A compressor (**10**) for compressing the nitrogen gas, and a cooling unit (**11**) for cooling the compressed nitrogen gas may be provided in the nitrogen gas pipeline (L**43**) between downstream from the warm end of the main heat exchanger (**1**) in the nitrogen gas pipeline (L**43**), and the nitrogen gas branch pipeline (L**431**).

[0047] A fluid introduced into the crude argon column (**5**) from the rectification portion (**42**) of the low-pressure rectification column (**4**) will be referred to as an "oxygen-containing fluid", and a liquid drawn from a location below the feed air introduction stage (e.g., the bottom of the nitrogen rectification column) will be referred to as an "oxygen-rich liquid". The oxygen-containing fluid may be a liquid or a gas-liquid mixture.

[0048] The air separation unit (A**2**) may comprise:

[0049] a bypass line (L**431***a*) which branches from the nitrogen gas branch pipeline (L**431**), bypasses the main heat exchanger (**1**) so that nitrogen gas is not introduced therein, and merges with the nitrogen gas branch pipeline (L**431**); and a regulating valve (V**1**) for regulating an amount of nitrogen gas circulating through the bypass line (L**431***a*).

[0050] The air separation unit (A**2**) may comprise:

[0051] a temperature measuring unit (**12**) for measuring the temperature of the nitrogen gas introduced into the nitrogen turbine (**8**).

[0052] The temperature measuring unit (**12**) may be provided in the bypass line (L**431***a*), in the nitrogen gas branch pipeline (L**431**), or in any line downstream from a merging point of the bypass line (L**431***a*) and the nitrogen gas branch pipeline (L**431**).

[0053] The regulating valve (V**1**) may regulate the amount of nitrogen gas circulating through the bypass line (L**431***a*) on the basis of the result of a temperature measurement by the temperature measuring unit (**12**) (e.g., above or below a threshold when the temperature is maintained within a predetermined temperature range).

[0054] The air separation units (A**3**, A**4**, A**5**) may comprise:

[0055] a nitrogen booster (**14**) which is provided in the nitrogen gas branch pipeline (L**431**) and boosts the pressure of the nitrogen gas to a predetermined pressure; a second cooling unit (**15**) for cooling the nitrogen gas pressure-boosted by the nitrogen booster (**14**); and

[0056] an expansion turbine (**81**) for expanding the nitrogen gas which has been cooled by the second cooling unit (**15**), once again introduced into the main heat exchanger (**1**), and drawn from an intermediate stage thereof.

[0057] The configuration above generates cold by means of a nitrogen booster-turbine configuration. That is to say, a portion of the low-pressure nitrogen gas is compressed by the nitrogen compressor (**10**), after which the nitrogen gas is expanded once the pressure thereof has been further boosted by means of the booster (**14**) driven by means of the expansion turbine (**81**). This pressure boosting process makes it possible to increase the amount of cold generated per flow rate by increasing a pressure difference in the expansion turbine (**81**), and a nitrogen molar flow rate required for generating cold can be reduced as a result.

[0058] The air separation units (A**4**, A**5**) may comprise:

[0059] a recycling nitrogen line (L**431***b*) which branches from the nitrogen gas branch pipeline (L**431**) inside the main heat exchanger (**1**), draws nitrogen gas out from the cold end of the main heat exchanger (**1**), and serves to introduce nitrogen gas into the rectification portion (**22**) or the upper portion (**23**) of the medium-pressure rectification column (**2**); and

[0060] a valve (V**2**) provided in the recycling nitrogen line (L**431***b*).

[0061] By virtue of this configuration, a portion of the nitrogen gas supplied from the nitrogen compressor (**10**) is cooled by the main heat exchanger (**1**) and supplied to the medium-pressure rectification column (**2**) When a liquid is produced in the air separation unit, a portion of the feed air is liquefied and introduced into the medium-pressure rectification column (**2**) or the low-pressure rectification column (**4**), but this is disadvantageous from the point of view of product yield because the vapour stream inside the rectification column decreases in proportion to liquefaction. In order to solve this problem, the vapour stream is increased by reintroducing nitrogen gas into the medium-pressure rectification column (**2**), making it possible to maintain the product gas yield.

[0062] The air separation unit (A**5**) may comprise:

[0063] a second nitrogen booster (**17**) which is provided in the nitrogen gas branch pipeline (L**431**) upstream from the first nitrogen gas booster (**14**) and boosts the pressure of the nitrogen gas to a predetermined pressure; and

[0064] a second cooling unit (**18**) which is provided in the nitrogen gas branch pipeline (L**431**) upstream from the first nitrogen booster (**14**) and cools the nitrogen gas pressure-boosted by the second nitrogen booster (**17**).

[0065] The second nitrogen booster (**17**) may be driven by means of the oxygen turbine (**9**).

[0066] By virtue of this configuration, the second nitrogen booster (**17**) is driven by means of the oxygen turbine (**9**). That is to say, a portion of the low-pressure nitrogen gas is compressed by the nitrogen compressor (**10**), after which the nitrogen gas is expanded once the pressure thereof has been further boosted by means of the second nitrogen booster (**17**) driven by means of the oxygen turbine (**9**). This pressure boosting process makes it possible to increase the amount of cold generated per flow rate by increasing a pressure difference in the expansion turbine, and a nitrogen molar flow rate required for generating cold can be reduced as a result.

[0067] The sub-cooler (**7**) uses a gas drawn from the low-pressure rectification column (**4**) or the crude argon condenser (**6**) to cool the liquid drawn from the medium-pressure rectification column (**2**). In this way, the amount of liquid vaporized by decompression when the liquid is introduced into the low-pressure rectification column (**4**) is reduced, and the amount of liquid contributing to rectification as a reflux liquid is increased, and therefore rectification efficiency can be improved.

[0068] Oxygen gas drawn from the gas phase in the refrigerant storage portion (**32**) of the nitrogen condenser (**3**) may be mixed with nitrogen gas or oxygen-rich liquid before being introduced into the oxygen turbine (**9**). In this way, it is possible to increase the cold which is generated by increasing the stream of gas expanded by the oxygen turbine (**9**), and it is furthermore possible to reduce safety risks, such as combustion caused by oxygen in the oxygen turbine (**9**). Liquid oxygen (LOX) extracted from the refrigerant storage portion (**32**) may be sub-cooled by the sub-cooler (**7**) (see FIG. **6**).

[0069] The air separation units (A**1**, A**2**, A**3**, A**4**, A**5**, A**6**) may include:

[0070] various measuring instruments such as flow rate measuring instruments, pressure measuring instruments, temperature measuring instruments, and liquid level measuring instruments;

[0071] various valves such as control valves and gate valves; and pipes for connecting each component.

BRIEF DESCRIPTION OF THE FIGURES

[0072] FIG. **1** is a drawing illustrating an air separation unit according to embodiment 1.

[0073] FIG. **2** is a drawing illustrating an air separation unit according to embodiment 2.

[0074] FIG. **3** is a drawing illustrating an air separation unit according to embodiment 3.

[0075] FIG. **4** is a drawing illustrating an air separation unit according to embodiment 4.

[0076] FIG. **5** is a drawing illustrating an air separation unit according to embodiment 5.

[0077] FIG. **6** is a drawing illustrating an air separation unit according to embodiment 6.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the Invention

[0078] Several embodiments of the present disclosure will be described below. The embodiments described below are given as an example of the present disclosure. The present disclosure is in no way limited by the following embodiments, and also includes a number of variants which are implemented within a scope that does not alter the gist of the present disclosure. It should be noted that not all the constituents described below are necessarily essential to the present disclosure. Upstream and downstream are based on a flow direction of a fluid (liquid or gas).

(Embodiment 1)

[0079] A first air separation unit A**1** according to embodiment **1** will be described with the aid of FIG. **1**.

[0080] The first air separation unit A**1** comprises: a main heat exchanger (**1**), a medium-pressure rectification column (**2**), a low-pressure rectification column (**4**), a crude argon column (**5**), a nitrogen condenser (**3**), a crude argon condenser (**6**), an oxygen turbine (**9**), a nitrogen compressor (**10**), and a nitrogen turbine (**8**).

[0081] The main heat exchanger **1** cools feed air introduced from a warm end and discharges the feed air from a cold end thereof. The cooled feed air is introduced into the medium-pressure rectification column **2** via a feed air pipeline L**1**.

[0082] The medium-pressure rectification column **2** comprises a bottom **21**, a rectification portion **22**, and a top **23**. The feed air pipeline L**1** is connected to the bottom **21**.

[0083] Oxygen-rich liquid that collects in the bottom **21** is delivered via a nitrogen-rich liquid pipeline L**21** to a rectification portion **42** of the low-pressure rectification column **4** after undergoing heat exchange in a sub-cooler **7**. A portion of the oxygen-rich liquid following heat exchange in the sub-cooler **7** is introduced into a refrigerant storage portion **61** of the crude argon condenser **6**.

[0084] A portion of the liquid nitrogen in the top **23** is delivered via a liquid nitrogen pipeline L**23** to a top **43** of the low-pressure rectification column **4** after undergoing heat exchange in the sub-cooler **7**. A liquid nitrogen branch pipeline L**231** is a line which branches from the liquid nitrogen pipeline L**23** downstream from the sub-cooler **7**, and extracts liquid nitrogen.

[0085] The nitrogen condenser **3** is provided above the top **23** of the medium-pressure rectification column **2**. A portion of the nitrogen gas (vapour stream) drawn from the top **23** of the medium-pressure rectification column **2** is introduced into the nitrogen condenser **3** via a reflux pipeline and is cooled (condensed) and liquefied by means of heat exchange with oxygen-rich liquid constituting a refrigerant. The liquid nitrogen which has been liquefied is returned to the top **23** of the medium-pressure rectification column **2** as a reflux liquid.

[0086] A liquid nitrogen extraction line L**31** is a line for extracting, as liquid oxygen (LOX), the refrigerant (oxygen-rich liquid) from the refrigerant storage portion **32** of the nitrogen condenser **3**.

[0087] The low-pressure rectification column **4** comprises a rectification portion **42** and a top **43**. The bottom thereof may also serve as the refrigerant storage portion **32** of the nitrogen condenser **3**.

[0088] An oxygen-containing fluid drawn from the rectification portion **42** of the low-pressure rectification column **4** is introduced into the bottom **51** of the crude argon column **5** via the oxygen-containing fluid pipeline L**421**.

[0089] The crude argon column **5** comprises a bottom **51**, a rectification portion **52**, and a top **53**.

[0090] A crude argon column-bottom fluid pipeline L**51** is a line for drawing a bottom fluid from the bottom **51** of the crude argon column **5**, and introducing the bottom fluid below a draw-out position of the oxygen-containing fluid pipeline L**421** in the rectification portion **42** of the low-pressure rectification column **4**.

[0091] The argon extraction line L**53** is a line for drawing a vapour stream or reflux liquid (crude argon-containing fluid) from the upper portion of the crude argon column **5**.

[0092] The vapour stream from the upper portion of the crude argon column **5** is introduced into the crude argon condenser **6** where it is condensed and drawn out as a reflux liquid.

[0093] The crude argon condenser pipeline L**62** is a line for drawing the upper vapour phase in the refrigerant storage portion **62** of the crude argon condenser **6**, and introducing same into the rectification portion **42** of the low-pressure rectification column **4** above the oxygen-rich liquid pipeline L**21**.

[0094] The oxygen-rich liquid drawn from the bottom **21** of the medium-pressure rectification column **2** is introduced from the warm end of the sub-cooler **7** and drawn from the cold end thereof. Furthermore, the vapour stream drawn from the upper portion **23** of the medium-pressure rectification column **2** is introduced from the warm end of the sub-cooler **7** and drawn from the cold end thereof. Furthermore, nitrogen gas drawn from the top **43** of the low-pressure rectification column **4** is introduced from the cold end of the sub-cooler **7** and drawn from the warm end thereof.

[0095] The oxygen turbine **9** expands and cools the oxygen gas drawn from the gas phase in the refrigerant storage portion **32** of the nitrogen condenser **3**, after the oxygen gas has undergone heat exchange in the main heat exchanger **1**.

[0096] An oxygen extraction line L**32** is a line which draws oxygen from an upper gas phase in the refrigerant storage portion **32** of the nitrogen condenser **3**, introduces the oxygen at an intermediate stage of the main-heat exchanger **1** where the oxygen is warmed and then drawn out and expanded by the oxygen turbine **9**, the oxygen then being once again introduced from the cold end of the main heat exchanger **1** and drawn from the warm end thereof, and extracted as product oxygen gas.

[0097] The nitrogen turbine **8** expands the nitrogen gas drawn from the top **43** of the low-pressure rectification column **4**, after said nitrogen gas has undergone heat exchange in the sub-cooler **7** and the main heat exchanger **1**, been compressed to a predetermined pressure in the nitrogen compressor **10**, cooled in the cooling unit **11**, and once again cooled in the main heat exchanger **1**.

[0098] The nitrogen gas drawn out from the top **43** of the low-pressure rectification column **4** is extracted as low-pressure nitrogen gas via the nitrogen gas pipeline L**43** and via the sub-cooler **7** and the main heat exchanger **1**.

[0099] The nitrogen compressor **10** and the cooling unit **11** are provided in the nitrogen gas pipeline L**43**, downstream from the warm end of the main heat exchanger **1**.

[0100] The nitrogen gas branch pipeline L**431** is a line which branches from the nitrogen gas pipeline L**43** downstream from the cooling unit **11**, once again introduces the nitrogen gas from the warm end of the main heat exchanger **1**, draws out nitrogen gas from an intermediate portion, the nitrogen gas then being expanded by the nitrogen turbine **8** and merged into the nitrogen gas pipeline L**43**.

[0101] In order to make the inlet temperature of the oxygen turbine **9** lower than the inlet temperature of the nitrogen turbine **8** in this embodiment **1**, the temperature of a gas drawn from a first intermediate portion **1***a* of the main heat exchanger **1** and delivered to the oxygen turbine **9** is lower than the temperature of a gas drawn from a second intermediate portion **1***b* of the main heat exchanger **1** and delivered to the nitrogen turbine **8**. For example, a position (first intermediate portion **1***a*) of an extraction nozzle of a pipe connected to the oxygen turbine **9** from the main heat exchanger **1** is disposed on the low temperature side of a position (second intermediate portion **1***b*) of an extraction nozzle of a pipe connected to the nitrogen turbine **8**.

(Embodiment 2)

[0102] An air separation unit A**2** according to embodiment 2 will be described with the aid of FIG. **2**. Reference numerals the same as those in embodiment 1 have the same functions, and therefore descriptions thereof may be omitted. The air separation unit A**2** comprises a bypass pipeline L**431***a*, a regulating valve V**1**, and a temperature measuring unit **12**.

[0103] The bypass line L**431***a* is a line which is provided in order to regulate the heat balance in the main heat exchanger **1**, branching from the nitrogen gas branch pipeline L**431**, bypassing the main heat exchanger **1** so that nitrogen gas is not introduced therein, and merging with the nitrogen gas branch pipeline L**431**.

[0104] The temperature measuring unit **12** measures the temperature of the nitrogen gas introduced into the nitrogen turbine **8**. In this embodiment, the temperature measuring unit **12** is provided in a line downstream from a merging point of the bypass line L**431***a* and the nitrogen gas branch pipeline L**431**.

[0105] The regulating valve V**1** regulates the amount of nitrogen gas circulating through the bypass line L**431***a* so that the temperature measured by the temperature measuring unit **12** is higher than the inlet temperature of the oxygen turbine **9** (a temperature value from a thermometer which is installed but not depicted).

[0106] The bypass line L**431***a* is provided from the nitrogen gas pipe at the warm end of the main heat exchanger **1** to a nitrogen turbine inlet pipe, and is configured to be capable of regulating the temperature so that the inlet temperature of the nitrogen turbine **8** is higher than the inlet temperature of the oxygen turbine **9**.

(Embodiment 3)

[0107] An air separation unit A**3** according to embodiment **3** will be described with the aid of FIG. **3**. Reference numerals the same as those in embodiment **1** have the same functions, and therefore descriptions thereof may be omitted. The air separation unit A**3** comprises a nitrogen booster **14** and a cooling unit **15**.

[0108] The nitrogen booster **14** is provided in the nitrogen gas branch pipeline L**431** upstream from the main heat exchanger **1**, and boosts the pressure of the nitrogen gas to a predetermined pressure.

[0109] The second cooling unit **15** cools the nitrogen gas pressure-boosted by the nitrogen booster **14** to a predetermined temperature.

[0110] An expansion turbine **81** expands the nitrogen gas which has been cooled by the second cooling unit **15**, once again introduced from the warm end of the main heat exchanger **1**, and drawn from an intermediate stage thereof.

(Embodiment 4)

[0111] An air separation unit A**4** according to embodiment **4** will be described with the aid of FIG. **4**. Reference numerals the same as those in embodiment **3** have the same functions, and therefore descriptions thereof may be omitted. The air separation unit A**4** comprises a recycling nitrogen line L**431***b*.

[0112] The recycling nitrogen line L**431***b* is a line which branches from the nitrogen gas branch pipeline L**431** inside the main heat exchanger **1**, draws nitrogen gas out from the cold end of the main heat exchanger **1**, and serves to introduce nitrogen gas into the rectification portion **22** or the upper portion **23** of the medium-pressure rectification column **2**.

[0113] A valve V**2** is provided in the recycling nitrogen line L**431***b* to regulate the start of introduction, stopping, and the introduction amount of the recycling nitrogen gas.

(Embodiment 5)

[0114] An air separation unit A**5** according to embodiment **5** will be described with the aid of FIG. **5**. Reference numerals the same as those in embodiment **4** have the same functions, and therefore descriptions thereof may be omitted. The air separation unit A**5** comprises a second nitrogen booster **17** and a second cooling unit **18**.

[0115] The second nitrogen booster **17** is provided in the nitrogen gas branch pipeline L**431** upstream from the first nitrogen booster **14**, and boosts the pressure of the nitrogen gas to a predetermined pressure.

[0116] The second cooling unit **18** is provided in the nitrogen gas branch pipeline L**431** upstream from the first nitrogen booster **14** and downstream from the second nitrogen booster **17**, and cools the nitrogen gas pressure-boosted by the second nitrogen booster **17** to a predetermined temperature.

[0117] The second nitrogen booster **17** is driven by means of the oxygen turbine **9**.

(Embodiment 6)

[0118] An air separation unit A**6** according to embodiment 6 will be described with the aid of FIG. **6**. Reference numerals the same as those in embodiment 1 have the same functions, and therefore descriptions thereof may be omitted. The air separation unit A**6** is configured without the crude argon column or the crude argon condenser.

[0119] The oxygen pipeline L**31** is a pipeline which introduces oxygen into the cold end of the sub-cooler **7** and draws oxygen from the warm end thereof.

(Example)

[0120] The results of a physical simulation of the air separation unit according to embodiment 3 will be presented.

[0121] Feed air at a temperature of 20.0° C., a pressure of 9.4 barA, and a flow rate of 1000 Nm^3/h is introduced from the warm end of the main heat exchanger, cooled to −163° C., and then introduced into the medium-pressure rectification column.

[0122] The medium-pressure rectification column comprises the nitrogen condenser at the top, and although the nitrogen gas at the top is condensed and returned to the medium-pressure rectification column top, a 424 Nm^3/h portion of the liquid nitrogen is drawn out and cooled to −184° C. in the sub-cooler, and supplied to the top of the low-pressure rectification column. An oxygen-rich liquid having an oxygen concentration of 36.4% is drawn at 576 Nm^3/h from the bottom of the medium-pressure rectification column and cooled to −170° C. in the sub-cooler, after which it is introduced at an intermediate stage of the low-pressure rectification column or the low-temperature side of the crude argon condenser.

[0123] Low-pressure nitrogen gas is drawn at 781 Nm^3/h from the top of the low-pressure rectification column, and drawn out at 18° C. and 2.4 barA through the sub-cooler and the main heat exchanger. Oxygen gas having an oxygen concentration of 99% is drawn at 211 Nm^3/h from the bottom of the low-pressure rectification column, heated to −126° C. in the main heat exchanger, and then expanded from 2.5 barA to 1.28 barA by the oxygen turbine. At this time, the oxygen turbine outputs 1.7 kW of work to the outside, and the oxygen gas is cooled to −149° C. The oxygen gas is reintroduced into the main heat exchanger where it is heated and then drawn from the warm end of the main heat exchanger.

[0124] A gas comprising 10% argon and 90% oxygen is introduced at 299 Nm^3/h to the bottom of the crude argon column where it is rectified, and argon is drawn from the column top at 8 Nm^3/h. 291 Nm^3/h of liquid is returned to the low-pressure rectification column from the bottom of the crude argon column.

[0125] Under these conditions, the cold required to liquefy 8 Nm^3/h corresponding to approximately 1% of the low-pressure nitrogen gas in order to produce liquid nitrogen is 1.1 KW, corresponding to 65% of the amount of cold generated by the oxygen turbine. In order to generate this cold, nitrogen gas at 20° C., 10 barA and 75 Nm^3/h is cooled to −119° C., expanded to 2.6 barA by the nitrogen turbine, and cooled to −164° C. This is then merged with low-pressure nitrogen gas supplied from the sub-cooler and is introduced into the main heat exchanger. The nitrogen turbine is capable of generating the cold required for this liquefaction, and therefore enables the heat balance in the air separation unit to be maintained even if liquid nitrogen is drawn out.

[0126] In the configurations of the embodiments above, the inlet temperature of the oxygen turbine is −126° C. while the inlet temperature of the nitrogen turbine is −119° C., thereby enabling gas to be drawn at a temperature 7° C. higher. In the turbine cycle, the amount of work provided to the outside can be increased when the gas is expanded at a higher temperature, but it may no longer be possible to supply the cold required for gas cooling in a low-temperature region. In this embodiment, when additional cold is required by the nitrogen turbine in order to liquefy the product gas, etc. while the base load of cold is supplied by the oxygen turbine, the cold can be efficiently generated using the synergistic effect with the oxygen turbine by expanding the nitrogen gas at a higher temperature than the oxygen turbine inlet temperature.

[0127] This configuration does not employ feed air or medium-pressure nitrogen which contribute to the vapour stream in the medium-pressure rectification column, so the yields of product nitrogen and product argon are unaffected. For example, when feed air is used as a cold source, around 7% of the feed air is expanded by the expansion turbine in order to generate cold, which means that it no longer contributes to rectification, and this affects the yield of nitrogen or argon by around 7%, so this embodiment also has the marked advantage of eliminating such an effect.

(Other Embodiments)

[0128] (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.

[0129] (2) Although not explicitly stated, control valves and gate valves, etc. may be installed in each line.

[0130] (3) Although not explicitly stated, pressure regulating devices and temperature measuring devices, etc. may be installed in each column in order to regulate pressure and regulate temperature.

[0131] 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.

[0132] The singular forms “a”, “an” and “the” include plural referents, unless the context clearly dictates otherwise.

[0133] “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” is defined herein as necessarily encompassing the more limited transitional terms “consisting essentially of” and “consisting of”; “comprising” may therefore be replaced by “consisting essentially of” or “consisting of” and remain within the expressly defined scope of “comprising”.

[0134] “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.

[0135] 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.

[0136] 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.

[0137] All references identified herein are each hereby incorporated by reference into this application in their entireties, as well as for the specific information for which each is cited.

KEY TO SYMBOLS

[0138] **1** . . . Main heat exchanger, **2** . . . Medium-pressure rectification column, **3** . . . Nitrogen condenser, **4** . . . Low-pressure rectification column, **5** . . . Crude argon column, **6** . . . Crude argon condenser, **8** . . . Nitrogen turbine, **9** . . . Oxygen turbine, **10** . . . Nitrogen compressor, **11** . . . Cooling unit

1: An air separation unit comprising:

a main heat exchanger comprising feed air introduced from a warm end thereof and drawn from a cold end thereof;

a medium-pressure rectification column into configured to introduce the feed air drawn from the main heat exchanger;

a nitrogen condenser into configured to introduce a vapour stream from the medium-pressure rectification column, the vapour stream being condensed and drawn out as a reflux liquid;

a low-pressure rectification column into configured to introduce an oxygen-rich liquid drawn from the medium-pressure rectification column;

an oxygen turbine for expanding and cooling an oxygen-rich gas drawn from the nitrogen condenser, after the oxygen-rich gas has undergone heat exchange in the main heat exchanger; and

a nitrogen turbine for expanding nitrogen gas drawn from the low-pressure rectification column, after said nitrogen gas has undergone heat exchange at least in the main heat exchanger, been compressed to a predetermined pressure and cooled, and once again cooled in the main heat exchanger,

wherein, an inlet temperature of the oxygen turbine is lower than an inlet temperature of the nitrogen turbine.

2: The air separation unit according to claim **1**, further comprising

a crude argon column into configured to introduce an oxygen-containing fluid drawn from the low-pressure rectification column; and

a crude argon condenser into configured to introduce a vapour stream from the crude argon column, the vapour stream being condensed and drawn out as a reflux liquid.

3: The air separation unit according to claim **1**, further comprising:

a nitrogen gas pipeline configured to draw nitrogen gas from the low-pressure rectification column and extracts nitrogen gas at least via the main heat exchanger;

a nitrogen gas branch pipeline configured to branch the nitrogen gas pipeline downstream from the main heat exchanger, configured to introduce the nitrogen gas from the warm end of the main heat exchanger, configured to draw out out nitrogen gas from an intermediate portion, the nitrogen gas then being expanded by the nitrogen turbine and merged into the nitrogen gas pipeline or extracted as nitrogen gas once again via the main heat exchanger;

a bypass line configured to branch from the nitrogen gas branch pipeline, configured to bypasds the main heat exchanger so that nitrogen gas is not introduced therein, and configured to merge with the nitrogen gas branch pipeline; and

a regulating valve for regulating an amount of nitrogen gas circulating through the bypass line.

4: The air separation unit according to claim **1**, comprising:

a nitrogen gas pipeline configured to draw nitrogen gas from the low-pressure rectification column and configured to extract nitrogen gas at least via the main heat exchanger;

a nitrogen gas branch pipeline configured to branch from the nitrogen gas pipeline downstream from the main heat exchanger, configured to introduce the nitrogen gas from the warm end of the main heat exchanger, configured to draw out nitrogen gas from an intermediate portion, the nitrogen gas then being expanded by the nitrogen turbine and merged into the nitrogen gas pipeline or extracted as nitrogen gas once again via the main heat exchanger;

a nitrogen booster which is provided in the nitrogen gas branch pipeline and configured to boost the pressure of the nitrogen gas to a predetermined pressure; and

a second cooling unit configured to cool the nitrogen gas pressure-boosted by the nitrogen booster.

5: The air separation unit according to claim **3**, further comprising a recycling nitrogen line configured to branch from the nitrogen gas branch pipeline inside the main heat exchanger, configured to draw nitrogen gas out from the cold end of the main heat exchanger, and configured to introduce nitrogen gas into the medium-pressure rectification column.

6: The air separation unit according to claim **3**, further comprising: a second nitrogen booster which is provided in the nitrogen gas branch pipeline and configured to boost the pressure of the nitrogen gas to a predetermined pressure; and

a second cooling unit which is provided in the nitrogen gas branch pipeline and configured to cool the nitrogen gas pressure-boosted by the second nitrogen booster.

7: The air separation unit according to claim **1**, further comprising a sub-cooler which is configured to accept an oxygen-rich liquid drawn from the medium-pressure rectification column introduced from a warm end and drawn from a cold end.

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