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(54) **CRYOGENIC DISTILLATION METHOD AND APPARATUS FOR PRODUCING PRESSURIZED AIR BY MEANS OF EXPANDER BOOSTER IN LINKAGE WITH NITROGEN EXPANDER FOR BRAKING**

(57) Provided are a method and apparatus for producing nitrogen and oxygen by means of cryogenic distillation of air. Nitrogen products are extracted only from the top of a tower. If a customer needs nitrogen with lower pressure, part of pure nitrogen which is partially located at a first nitrogen product pressure is reheated in a main heat exchanger, then decompressed to a second nitrogen product pressure by means of a nitrogen expander, further reheated by means of the main heat exchanger, and output as a low-pressure nitrogen product. The nitrogen expander can be braked by an expander booster for compressing air. By means of the method, nitrogen with different pressures can be suitably produced, and moreover, the energy consumption for producing the pressurized air can be reduced by utilizing the expansion work of nitrogen.

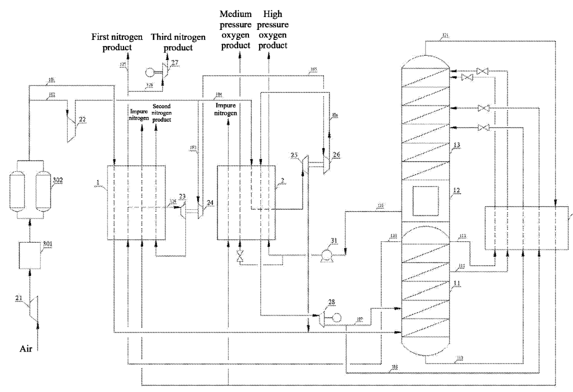

Fig. 1

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Description

Technical Field

[0001] The present invention relates to a low-temperature rectification air separation process and device.

Background Art

[0002] The use of cryogenic distillation to separate air into nitrogen and oxygen products is a common and mature technology. At least two air separation towers operating at different pressures - a medium pressure tower and a low pressure tower - are brought into communication by means of heat exchange via a main condensing evaporator. A pressurized, purified and cooled air feed gas is input into the medium pressure tower and/or the low pressure tower, and by means of rectification, gaseous and/or liquid nitrogen and oxygen are obtained. All or part of the nitrogen and oxygen undergo heat exchange with the air feed gas in the main heat exchanger to obtain gaseous nitrogen and oxygen products at room temperature. The design of an air separation device and process is generally based on the requirements of customers for the status, pressure and output of nitrogen and oxygen products.

[0003] When it is necessary to produce oxygen and/or nitrogen products with a higher pressure - for example, greater than 40 bara, an external pressurization method by which room temperature oxygen or nitrogen, which has been reheated by means of the main heat exchanger, is pressurized by means of a corresponding booster, or an internal pressurization method by which low-temperature liquid oxygen or liquid nitrogen is boosted to a desired pressure by means of a pump and then reheated by means of the main heat exchanger may be selected. In particular, when producing high pressure oxygen, due to production safety and equipment cost considerations, the internal pressurization process is generally used.

[0004] During the internal pressurization process, a high pressure warm stream is required for evaporating and vaporizing the high pressure liquid oxygen in the main heat exchanger, wherein this warm stream is generally a high pressure air feed gas, or may also be circulating high pressure nitrogen. If a high pressure air feed gas is used, the air feed gas that has reached a pressure for the medium pressure tower by means of a main air compressor needs to be further pressurized to a higher pressure by means of a booster, and this is an energy-consuming process.

Summary of the Invention

[0005] A technical problem to be solved by the present invention is to improve the utilization of the rectification capacity of an air separation tower, especially a low pressure tower.

[0006] Another technical problem to be solved by the present invention is to reduce the energy consumption required for the pressurization of an air feed gas.

[0007] Still another technical problem to be solved by the present invention is how to flexibly provide nitrogen with different output and pressure to a customer.

[0008] In one aspect, the present invention provides a method for producing nitrogen and oxygen by means of the cryogenic distillation of air, comprising: providing a first tower working at a higher pressure, i.e. a medium pressure tower, and a second tower working at a lower pressure, i.e. a lower pressure tower, wherein the first tower and the second tower are brought into communication by means of heat exchange via a main condensing evaporator; providing at least one air pre-cooling system, one air purification system, one main air compressor, at least one air booster, at least one main heat exchanger, and one supercooler; further treating an air feed gas, which has been pressurized to a first pressure range by means of the main air compressor, by means of the pre-cooling system and the purification system, then sending part of the air feed gas to the main heat exchanger for heat exchange with gas products produced by means of rectification and then to the first tower, subjecting the other part of the air feed gas to pressurization by means of the air booster and several stages of expander boosters, to heat exchange in the main heat exchanger with gas and liquid products produced by means of rectification and then to expansion or throttling for decompression to the first pressure range, and then sending this other part to the first tower, or supercooling a part of separated liquid by means of the supercooler, followed by throttling and sending to the second tower; rectifying the air feed gas in the first tower, extracting oxygen-enriched liquid air at the bottom of the first tower, pure liquid nitrogen at the top, and optionally impure liquid nitrogen in the middle part, and sending same to the supercooler for supercooling and then to the second tower as reflux liquids; extracting pure liquid oxygen in the main condensing evaporator, and sending the pure liquid oxygen to a liquid oxygen pump for pressurization and then to the main heat exchanger for heat exchange with the air feed gas pressurized by means of the air booster and the several stages of expander boosters, followed by evaporation and vaporization for output as a product; extracting impure nitrogen from the second tower, and sending the impure nitrogen to the supercooler for warming and then to the main heat exchanger for further reheating; extracting pure nitrogen at a first nitrogen product pressure from the top of the first tower and sending the pure nitrogen to the main heat exchanger for reheating. In the method, a part of pure nitrogen at the first nitrogen product pressure is partially reheated in the main heat exchanger, decompressed to a second nitrogen product pressure by means of a nitrogen expander, then further reheated by means of the main heat exchanger, and output as a product; and the nitrogen expander is braked by means of a first expander booster, the first expander booster further pressurizes the part of air feed gas that has been pressurized by means of the air booster and reaches a second pressure range to a third pressure range, and the air feed gas within the third pressure range enters, directly or optionally after undergoing further pressurization, the main heat exchanger for heat exchange with the gas and liquid products produced by means of rectification, and is then decompressed to the first pressure range by means of a liquid expander and then sent to the first tower, or a part of liquid is supercooled by means of the supercooler, then throttled and sent to the second tower.

[0009] In another aspect, the present invention further provides an apparatus for producing nitrogen and oxygen by means of the cryogenic distillation of air, comprising: a first tower working at a higher pressure and a second tower working at a lower pressure, wherein the first tower and the second tower are brought into communication by means of heat exchange via a main condensing evaporator; at least one air pre-cooling system, one air purification system, one main air compressor, one air booster, a first expander booster, at least one main heat exchanger, one nitrogen expander, at least one liquid expander, one liquid oxygen pump and one supercooler; a pipeline for sending an air feed gas to the first tower via the main air compressor, the air pre-cooling system, the air purification system and the main heat exchanger; a pipeline for sending oxygen-enriched liquid air at the bottom of the first tower to the supercooler for supercooling and to the second tower; a pipeline for sending pure liquid nitrogen at the top of the first tower to the supercooler for supercooling and to the upper part of the second tower; optionally, a pipeline for sending impure liquid nitrogen in the middle part of the first tower to the supercooler for supercooling and to the second tower; a pipeline for extracting impure nitrogen from the second tower and sending the impure nitrogen to the supercooler for warming and to the main heat exchanger for reheating; a pipeline for extracting pure liquid oxygen from the main condensing evaporator and sending the pure liquid oxygen to the liquid oxygen pump for pressurization and then through the main heat exchanger; and a pipeline for extracting pure nitrogen from the top of the lower tower and sending the pure nitrogen to the main heat exchanger; and further comprising a pipeline for sending a part of pure nitrogen, which has been reheated, from the main heat exchanger to the nitrogen expander, and returning the expanded pure nitrogen to the main heat exchanger for reheating, wherein the nitrogen expander is braked by means of a first expander booster, and the main air compressor, the air booster and the first expander booster are sequentially connected in series, and are connected to the main heat exchanger, the liquid expander and then the lower tower via a pipeline.

[0010] In the present invention, a nitrogen product is only extracted from the top of the first tower, and the pressure of this nitrogen product is generally a medium pressure of 5-6 bara. If a customer needs nitrogen with a higher pressure, the reheated nitrogen can be further pressurized using a booster. If a customer needs nitrogen with a lower pressure, instead of the common practice of extracting low pressure nitrogen from a pure nitrogen tower at the top of a low pressure tower, the present invention uses the expansion of medium pressure nitrogen to obtain desired low pressure nitrogen. Furthermore, the above-mentioned nitrogen expander may be braked by means of an expander booster for compressing air. It can be seen therefrom that the present invention can flexibly produce nitrogen with different pressures, while the energy consumption for producing pressurized air can be reduced by utilizing the expansion work of nitrogen.

[0011] After medium pressure nitrogen is extracted at the top of the first tower, the amount of pure liquid nitrogen that can be used as a reflux liquid to the second tower will be reduced accordingly. This will make greater use of the rectification capacity of the second tower, and will also reduce the required diameter of the second tower, making the transportation thereof more convenient.

Brief Description of the Drawings

[0012] The drawings of the present disclosure are only intended to illustrate the present invention for construing and explaining the spirit of the present invention, but do not limit the present invention in any respect.

Figure 1 is an embodiment of the present invention, wherein a first expander booster and a second expander booster are connected in series.

Figure 2 is another embodiment of the present invention, wherein a first expander booster and a second expander booster are connected in parallel.

Figure 3 is a comparative solution for the present invention, in which no nitrogen expander is comprised.

Detailed Description of Embodiments

[0013] In the present disclosure, the term "air feed gas" refers to a mixture mainly comprising oxygen and nitrogen.

[0014] The term "pure nitrogen" covers gaseous fluids with a nitrogen content of not less than 99 mole percent, and the term "impure nitrogen" covers gaseous fluids with a nitrogen content of not less than 95 mole percent, with the content of nitrogen in the "impure nitrogen" being less than that in the "pure nitrogen".

[0015] The term "oxygen-enriched liquid air" refers to a liquid fluid with a molar percentage of oxygen greater than 30, and the term "pure liquid oxygen" covers liquid fluids with a molar percentage of oxygen greater than 99, with the content of oxygen in the "pure liquid oxygen" being higher than that in the "oxygen-enriched liquid air".

[0016] The term "pure liquid nitrogen" refers to a liquid fluid with a molar percentage of nitrogen greater than 99, and the term "impure liquid nitrogen" refers to a liquid fluid with a molar percentage of nitrogen greater than 96, with the content of nitrogen in the "impure liquid nitrogen" being less than that in the "pure liquid nitrogen".

[0017] The low temperature rectification of the present disclosure is a rectification method carried out at least in part at a temperature of 150 K or less. "Tower" herein means a distillation or fractionation tower or zone in which liquid and gas phases come into countercurrent contact for effectively separating a fluid mixture. The operating pressure of the "first tower" in the present disclosure is generally 5 to 6.5 bara, which is higher than the general operating pressure of the "second tower" by 1.1 to 1.5 bara. The second tower can be installed vertically at the top of the first tower or the two towers are installed side by side. The "first tower" is also generally referred to as a medium pressure tower or a lower tower, and the "second tower" is also generally referred to as a low pressure tower or an upper tower. The main condensing evaporator is generally located at the top of the "first tower", and it can make pure nitrogen produced at the top of the first tower condense by means of heat exchange with pure liquid oxygen produced at the bottom of the second tower to obtain pure liquid nitrogen at the top of the first tower, while the liquid oxygen is partially evaporated. Types for the main condensing evaporator include a tube and shell type, a falling film type, an immersion bath type, etc., and in the present invention, an immersion bath type condensing evaporator may be used.

[0018] The air pre-cooling system in the present invention is used for pre-cooling high temperature air (70-120°C) discharged from the main air compressor to a temperature suitable for entering the air purification system (generally 10-25°C). High-temperature air generally comes into contact with ordinary circulating cooling water and low-temperature water (generally 5-20°C) in an air cooling tower for heat exchange to achieve the purpose of cooling. Low-temperature water can be obtained by bringing ordinary circulating cooling water into contact with gas products or byproducts produced by the air separation apparatus, such as contact with impure nitrogen for heat exchange, or by means of a refrigerator.

[0019] The air purification system refers to a purification device that removes dust, water vapor, CO_2, hydrocarbons etc. from the air. In the present invention, a pressure swing adsorption method is generally used, wherein an adsorbent is involved which may optionally be a molecular sieve plus alumina, or a molecular sieve only.

[0020] In the main heat exchanger, the compressed, pre-cooled and purified air feed gas undergoes non-contact heat exchange with gas and/or liquid products produced by means of rectification, and is cooled close or equal to the rectification temperature of the first tower, generally less than 150 K. Common main heat exchangers include split or integrated types, etc. The main heat exchangers are divided into high pressure (> 20 bara pressure) and low pressure (< 20 bara pressure) heat exchangers according to suitable pressure ranges. In the present invention, both a high pressure plate heat exchanger and a low pressure plate heat exchanger, or an integral combined heat exchanger may be used.

[0021] In the present disclosure, the first pressure range is consistent with the range of the working pressure of the first tower or medium pressure tower, and is generally 5 to 6 bara, and the air feed gas at atmospheric pressure can be compressed by the main air compressor to reach this pressure range. The second pressure range is a pressure range achieved by pressurizing the air feed gas within the first pressure range by means of the air booster, and is generally 40 to 60 bara. The third pressure range is achieved by further pressurizing the air feed gas within the second pressure range by means of the first expander booster and/or the second expander booster, and is generally 60 to 75 bara. The air feed gases within the second and third pressure ranges are required to be capable of exchanging heat with pressurized liquid oxygen in the main heat exchanger and causing same to evaporate and vaporize, and therefore, the specific pressure thereof is determined by the pressure of the liquid oxygen that needs to be vaporized.

[0022] The first nitrogen product pressure refers to the pressure of the pure nitrogen extracted from the top of the first tower or medium pressure tower, and is generally 4 to 5 bara. According to customer requirements, the pure nitrogen with the first nitrogen product pressure can be expanded and decompressed to obtain the second nitrogen product pressure, which is generally about 1.1 bara; alternatively, the pure nitrogen with the first nitrogen product pressure can be pressurized by means of the nitrogen booster to obtain the third nitrogen product pressure, which is generally greater than 7 bara. The second and third nitrogen product pressures can both be flexibly determined according to customer requirements.

[0023] The Rahman's principle points out that when the upper tower or the low pressure tower is used to produce pure oxygen, the rectification capacity of the low pressure tower is not fully utilized. In the present invention, one or more of the following measures are used to improve this situation, in order to increase the efficiency of the entire air separation system, reduce energy consumption, and even reduce the volume of the tower. One of the measures is to introduce part of the air feed gas directly into the upper tower, i.e., the low pressure tower, so as to utilize the excess rectification capacity of this tower; a second one of the measures is to draw the pure nitrogen produced at the top of the medium pressure tower as a nitrogen product, and correspondingly, the amount of pure liquid nitrogen obtained after condensation by the main condenser will be reduced, that is, the amount of the reflux liquid sent to the low pressure tower will be reduced. On the one hand, the reduction of the reflux liquid will make further use of the rectification capacity of the low pressure tower; on the other hand, the reduction of the reflux liquid requires a reduction in the processing capacity of the low pressure tower, and the diameter of the low pressure tower can be reduced accordingly, causing easier transportation. Furthermore, compared with pure nitrogen with a pressure of about 1 to 2 bara extracted from the top of the low pressure tower as a nitrogen product, the pressure of pure nitrogen drawn from the top of the medium pressure tower is generally 4 to 5 bara. If the pressure of a nitrogen product required by a customer is greater than 4 to 5 bara, such as 10 bara, the energy consumption for pressurizing the pure nitrogen extracted from the medium pressure tower to 10 bara is greatly reduced than that for pressurizing the pure nitrogen extracted from the low pressure tower to 10 bara. If the pressure of a nitrogen product required by a customer is less than 4 to 5 bara, such as 1 bara, the pure nitrogen extracted from the medium pressure tower can be expanded to 1 bara, and the expansion work can be used for power generation or a shaft-linked expander booster, thereby reducing the energy consumption of the entire air separation system.

[0024] As shown in Figure 1, after air that has been pressurized to 6 bara in a main air compressor 21 is pre-cooled by means of a pre-cooling system and purified by means of a purification system, part 101 of the air enters a low pressure main heat exchanger 1 for indirect heat exchange with medium pressure pure nitrogen 123 resulting from rectification and part of impure nitrogen 121 for cooling to about -170°C and is then sent to the lower part of a first tower 11 for rectification. The other part 102 thereof is further pressurized to about 52 bara by means of an air booster 22, and then divided into two streams, wherein one stream 103 thereof is pressurized by means of a first expander booster 24 to become a stream 105 of 58 bara, and all is sent to a second expander booster 26 for further pressurization to become a stream 106 of 77 bara; and the other stream 104 of 102 is sent to a high pressure main heat exchanger 2, partially cooled, then extracted from the middle part, decompressed to 6 bara by means of an air expander 25, and then also sent to the lower part of the first tower 11 for rectification. Since the stream 105 that enters the second expander compressor 26 all comes from the first expander booster 24, the two form a series. The first expander booster 24 and the second expander booster 26 are respectively linked with a nitrogen expander 23 and the air expander 25, and absorb the work done by the expanders. The stream 106 pressurized to 77 bara enters the high pressure main heat exchanger 2 for indirect heat exchange with pure liquid oxygen 122, which has been pressurized to 88 bara, and part of impure liquid nitrogen 121 for condensation into a liquid while the high pressure pure liquid oxygen 122 evaporates and vaporizes and is output as a high pressure oxygen product. The condensed air feed gas is decompressed to 6 bara by means of the liquid expander 28 and then separated into gas and liquid phases, one of which is a gaseous stream 107 that is directly sent to the lower part of the first tower 11, and the other one of which is a part of liquid stream 108 that is supercooled by means of a supercooler 3 and then sent to the middle part of the second tower 13.

[0025] The air feed gas introduced into the first tower 11 is rectified in the first tower to produce oxygen-enriched liquid air 110 at the bottom of the tower and pure nitrogen at the top of the tower. By means of indirect heat exchange in the main condensing evaporator 12 with the liquid oxygen produced at the bottom of the second tower, a part of pure nitrogen is condensed into pure liquid nitrogen. The part of pure liquid nitrogen mentioned above is used as a reflux liquid to the first tower. Optionally, a part is sent to a storage tank as a liquid nitrogen product, and the other part 112 is supercooled and then input into the upper part of the second tower 13 as a reflux liquid. Furthermore, gases that are supercooled and input into the second tower also include the oxygen-enriched liquid air 110, and optionally, the impure liquid nitrogen 111 extracted from the middle part of the first tower 11 and the part of liquid air feed gas 108. The above-mentioned streams are throttled and decompressed to about 1.3 to 1.4 bara and then transported to the second tower 13, and participate in rectification therein, and then, the impure nitrogen 121 with a pressure of about 1.3 bara can be extracted from the upper part of the second tower, while the pure liquid oxygen 122 with a pressure of about 1.4 bara is obtained at the bottom of the second tower. When a customer needs a high pressure oxygen product, the pure liquid oxygen can be pressurized to about 88 bara by means of a liquid oxygen pump 31, and then evaporated and vaporized by the high pressure air feed gas 106, 104 in the high pressure main heat exchanger 2 to obtain the high pressure oxygen product. When a customer also needs a medium pressure oxygen product, a part of high pressure liquid oxygen from the liquid oxygen pump can be throttled and decompressed to obtain medium pressure liquid oxygen with a pressure of about 30 bara, which is then similarly evaporated and vaporized by the high pressure air feed gas 106, 104 in the high pressure main heat exchanger 2 to obtain the medium pressure oxygen product.

[0026] In this embodiment, the only nitrogen product is the medium pressure pure nitrogen 123 with a pressure of about 5.5 bara drawn from the top of the first tower 11. When a customer needs both low pressure and high pressure nitrogen products, the following operations can be carried out. In the middle part of the low pressure main heat exchanger 1, part 124 of the medium pressure pure nitrogen 123, which has been partially reheated, is extracted, decompressed to a desired pressure, which is referred to as a second nitrogen product pressure, by means of the nitrogen expander 23, then returned to the main heat exchanger, and completely reheated to obtain a second nitrogen product. The nitrogen expander 23 is braked by means of the first expander booster 24, thereby converting the expansion work into energy required for the compressed air feed gas. After the remaining part of the medium pressure pure nitrogen 123 is completely reheated by means of the low pressure main heat exchanger 1, this remaining part can be output at the first nitrogen product pressure as a first nitrogen product, or pressurized to a third nitrogen product pressure, as required by a customer, by means of a nitrogen booster and output as a third nitrogen product.

[0027] The main difference between the embodiments shown in Figure 2 and Figure 1 is the connection relationship between the first expander compressor 24 and the second expander compressor 26. In Figure 2, the two are connected in parallel. Specifically, after air feed gas that has been pressurized to 6 bara in a main air compressor 21 is pre-cooled by means of a pre-cooling system and purified by means of a purification system, part 101 of the air feed gas enters a low pressure main heat exchanger 1 for indirect heat exchange with medium pressure pure nitrogen 123 resulting from rectification and part of impure nitrogen 121 for cooling to about -170°C and is then sent to the lower part of a first tower 11 for rectification. The other part 102 thereof is further pressurized to about 52 bara by means of an air booster 22, and then divided into three streams, wherein one stream 115 thereof is pressurized by means of the first expander booster 24 to become a stream 116 of 76 bara; another stream 117 of 102 is sent to a high pressure main heat exchanger 2, partially cooled, then extracted from the middle part, decompressed to 6 bara by means of an air expander 25, and then also sent to the lower part of the first tower 11 for rectification; a third stream 118 of 102 is input into the second expander booster 26 and then also pressurized to form a stream 119 of 76 bara, which is mixed with the stream 116, then enters the high pressure main heat exchanger 2 for indirect heat exchange with pure liquid oxygen 122, which has been pressurized to 88 bara, and part of impure liquid nitrogen 121 for partial condensation into a liquid while the high pressure pure liquid oxygen 122 evaporates and vaporizes and is output as a high pressure oxygen product. Since the respective streams that enter the first and second expander compressors both come from a pressurizing end of the air booster 22, the two form a parallel connection. The condensed air feed gas 120 is decompressed to 6 bara by means of a liquid expander 28 and can be then separated into two streams by means of a gas-liquid separator, one of which is a gaseous stream 107 that is directly sent to the lower part of the first tower 11, and the other one of which is a liquid stream 108 that is supercooled by means of a supercooler 3 and then sent to the middle part of the second tower 13. The first expander booster 24 and the second expander booster 26 are respectively linked with a nitrogen expander 23 and the air expander 25, and absorb the work done by the expanders.

[0028] The rest of the embodiment shown in Figure 2 is the same as that of the embodiment shown in Figure 1. Both are examples for the implementation of the present invention, but do not limit the spirit and scope of the present invention in any way.

[0029] The following simulation calculations compare the operating costs of the air separation apparatus. Figure 2 shows a process flow as an embodiment according to the present invention, and Figure 3 shows a process flow as a comparative example. In Figure 3, as compared with Figure 2, the upper part of a second tower is provided with a pure nitrogen tower 14, and low pressure pure nitrogen 140 with a pressure of about 1.3 bara is directly extracted from the top of the pure nitrogen tower. The low pressure pure nitrogen 140 is reheated by means of a supercooler 3 and a main heat exchanger 1 and then output as a second nitrogen product. In Figure 3, medium pressure pure nitrogen 123 with a pressure of about 5.5 bara is still extracted from the top of a first tower; however, all of this stream is reheated by means of the main heat exchanger 1 and then used as a first nitrogen product, or alternatively, part of this stream is further pressurized and then output as a third nitrogen product. Correspondingly, the comparative example of Figure 3 does not have a nitrogen expander 23 and a first expander booster 24 in linkage therewith. Specifically, after air feed gas that has been pressurized to 6 bara in a main air compressor 21 is pre-cooled by means of a pre-cooling system 301 and purified by means of a purification system 302, part 101 of the air feed gas enters a low pressure main heat exchanger 1 for indirect heat exchange with medium pressure pure nitrogen 123 resulting from rectification and part of impure nitrogen 121 and low pressure pure nitrogen 140 for cooling to about -170°C and is then sent to the lower part of a first tower 11 for rectification. The other part 102 thereof is further pressurized to about 51 bara by means of an air booster 22, and then divided into two streams, wherein one stream 131 is sent to a high pressure main heat exchanger 2, partially cooled, then extracted from the middle part, and decompressed by means of an air expander 25 to become a stream 132 of 6 bara, which is then also sent to the lower part of the first tower 11 for rectification; and the other stream 133 is pressurized to 76 bara by means of a second expander booster 26, then enters the high pressure main heat exchanger 2 for indirect heat exchange with pure liquid oxygen 122, which has been pressurized to 88 bara, and part of impure liquid nitrogen 121 for partial condensation into a liquid while the high pressure pure liquid oxygen 122 evaporates and vaporizes and is output as a high pressure oxygen product. The condensed air feed gas is decompressed to 6 bara by means of a liquid expander 28 and can be then separated into two streams by means of a gas-liquid separator, one of which is a gaseous stream 107 that is directly sent to the lower part of the first tower 11, and the other one of which is a liquid stream 108 that is supercooled by means of a supercooler 3 and then sent to the middle part of the second tower 13. The rest of this comparative example is the same as that of the embodiment shown in Figure 2.

[0030] The simulation calculations listed in the following table are carried out using ASPEN software for an air separation system with an oxygen output of 100,000 Nm^3/h. In the air separation system, a main heat exchanger is involved which is of an aluminum plate-fin type, and a main air compressor (MAC) and an air booster (BAC) are involved which are both steam turbines driven by high pressure steam. The calculation of the operating cost is based on a high pressure steam price of 100 RMB/ton and is evaluated based on 5 years of operation.

Table 1. Comparison of operating costs

Category	Unit	Comparative example	Embodiment
Recovery of O_2	%	99.65%	99.00%
Medium pressure pure nitrogen extraction	Nm^3/h	13000	40000
Low pressure pure nitrogen extraction	Nm^3/h	27000	None
Flow rate of conversion of medium pressure pure nitrogen to low pressure pure nitrogen	Nm^3/h	0	27000
Power of MAC	KW	40,339	40,587
Power of BAC	KW	20,307	19,303
Total power of MAC + BAC	KW	60,646	59,890
Δ (Total power of MAC + BAC)	KW	0.0	-756
High pressure steam consumption	Ton/hour	200.3	197.7
Δ (High pressure steam consumption)	Ton/hour	0.0	-2.569
Operating costs (total of 5 years)	Mrmb	801.2	790.9
Δ (Operating costs (total of 5 years))	Mrmb	0.0	-10.3

[0031] Due to the extraction of additional 27000 Nm^3/h of medium pressure pure nitrogen, the recovery of O_2 obtained according to the present invention is slightly lower than that of the comparative example; however, the loss here is much less than the overall energy saving achieved by the present invention. In the above table, the "medium pressure pure nitrogen extraction" refers to the flow rate of the medium pressure pure nitrogen extracted from the top of the first tower, the "low pressure pure nitrogen extraction" refers to the flow rate of the low pressure pure nitrogen extracted from the top of the pure nitrogen tower, and the "flow rate of conversion of medium pressure pure nitrogen to low pressure pure nitrogen" refers to the flow rate of the part of medium pressure pure nitrogen that is drawn from the middle part of the main heat exchanger and sent to the nitrogen expander 23. In the present invention, due to the utilization of the work done by the nitrogen expander, the work required for producing the air feed gas with substantially the same pressure and flow rate by the air booster (BAC) is reduced, and the corresponding high pressure steam consumed is also reduced. Based on a total of five years, an operating cost of about 10 million can be saved.

Claims

1. A method for producing nitrogen and oxygen by means of the cryogenic distillation of air, comprising:

(a) providing a first tower (11) working at a higher pressure and a second tower (13) working at a lower pressure, wherein the first tower and the second tower are brought into communication by means of heat exchange via a main condensing evaporator (12);
(b) providing at least one air pre-cooling system, one air purification system, one main air compressor (21), at least one air booster (22), at least one main heat exchanger (1, 2), and one supercooler (3);
(c) further pre-cooling and purifying an air feed gas, which has been pressurized to a first pressure range by means of the main air compressor (21), then sending part (101) of the air feed gas to the main heat exchanger (1) for heat exchange with gas products produced by means of rectification and then to the first tower (11), subjecting the other part (102) of the air feed gas to pressurization by means of the air booster (22) and several stages of expander boosters (24, 26), to heat exchange in the main heat exchanger (2) with gas and liquid products produced by means of rectification and then to expansion or throttling for decompression to the first pressure range, and then sending this other part to the first tower (11), or supercooling a part by means of the supercooler (3), followed by throttling and sending to the second tower (13);
(d) rectifying the air feed gas in the first tower (11), extracting oxygen-enriched liquid air (110) at the bottom of the first tower, pure liquid nitrogen (112) at the top, and optionally impure liquid nitrogen (111) in the middle part, and sending same to the supercooler (3) for supercooling and then to the second tower (13) as reflux liquids;

(e) extracting pure liquid oxygen (122) in the main condensing evaporator (12), and sending the pure liquid oxygen to a liquid oxygen pump (31) for pressurization and then to the main heat exchanger (2) for heat exchange with the air feed gas pressurized by means of the air booster (22) and the several stages of expander boosters (24, 26), followed by evaporation and vaporization for output as a product;
(f) extracting impure nitrogen (121) from the second tower (13), and sending the impure nitrogen to the supercooler (3) for warming and then to the main heat exchanger (1, 2) for further reheating; and
(g) extracting pure nitrogen (123) at a first nitrogen product pressure from the top of the first tower (11) and sending the pure nitrogen to the main heat exchanger (1) for reheating,

wherein a part of pure nitrogen (124) at the first nitrogen product pressure is partially reheated in the main heat exchanger, decompressed to a second nitrogen product pressure by means of a nitrogen expander (23), then further reheated by means of the main heat exchanger (1), and output as a product; and the nitrogen expander (23) is braked by means of a first expander booster (24), the first expander booster (24) further pressurizes the part of air feed gas that has been pressurized by means of the air booster (22) and reaches a second pressure range to a third pressure range, and the air feed gas within the third pressure range enters, directly or optionally after undergoing further pressurization, the main heat exchanger (2) for heat exchange with the gas and liquid products produced by means of rectification, and is then decompressed to the first pressure range by means of a liquid expander (28) and then sent to the first tower (11), or a part of decompressed liquid is supercooled by means of the supercooler (3), then throttled and sent to the second tower (13).

2. The method of claim 1, wherein the main heat exchangers include a high pressure plate heat exchanger and a low pressure plate heat exchanger, or an integral combined heat exchanger.

3. The method of claim 2, wherein the part of air feed gas that has been pressurized by means of the air booster (22) and reaches the second pressure range is partially cooled in the main heat exchanger, then decompressed to the first pressure range by means of an air expander (25), and then sent to the first tower.

4. The method of claim 3, wherein the nitrogen expander (25) is braked by means of a second expander booster (26), the second expander booster (26) further pressurizes the air feed gas that has been pressurized by means of the air booster (22) and reaches the second pressure range to the third pressure range, and the air feed gas within the third pressure range enters the main heat exchanger (2) for heat exchange with the gas and liquid products produced by means of rectification, and is then decompressed to the first pressure range by means of the liquid expander (28) and then sent to the first tower.

5. The method of claim 4, wherein the air feed gas that has been pressurized by means of the air booster (22) and reaches the second pressure range is divided into three parts, wherein a first part (115) is pressurized to the third pressure range by means of the first expander booster (24); a second part (117) is partially cooled in the main heat exchanger, then decompressed to the first pressure range by means of the air expander (25), and then sent to the first tower (11); and a third part (118) is pressurized to the third pressure range by means of the second expander booster (26), the pressurized first part (116) and third part (119) of air feed gas are combined, then sent to the main heat exchanger (2) for heat exchange with the gas and liquid products produced by means of rectification, then decompressed to the first pressure range by means of the liquid expander (28) and then sent to the first tower.

6. The method of claim 3, wherein the nitrogen expander (25) is braked by means of a second expander booster (26), the second expander booster (26) further pressurizes the air feed gas (105) that has been pressurized by means of the first expander booster (24), the air feed gas is sent to the main heat exchanger (2) for heat exchange with the gas and liquid products produced by means of rectification, then decompressed to the first pressure range by means of the liquid expander (28) and then sent to the first tower (11).

7. The method of claim 6, wherein the air feed gas (105) that has been pressurized by means of the first expander booster (24) is all sent to the second expander booster (26) for further pressurization.

8. The method of any one of claims 4-7, wherein the liquid expander (28) is braked by means of an electric generator.

9. The method of any one of claims 1-7, wherein a part of the liquid air feed gas (108) within the first pressure range cooled by means of the main heat exchanger (1, 2) is supercooled by means of the supercooler (3), then throttled and sent to the second tower (13) as a reflux liquid.

10. The method of any one of claims 1-7, wherein the pure liquid oxygen (122) extracted in the main condensing evaporator (12) is partially supercooled by means of the supercooler and then sent to a liquid oxygen storage tank.

11. The method of any one of claims 1-7, wherein the pure liquid oxygen (122) extracted in the main condensing evaporator (12) is pressurized by means of the liquid oxygen pump (31), and a part is expanded or throttled for decompression, and then sent to the main heat exchanger (2) for heat exchange with the air feed gas, followed by evaporation and vaporization for output as a product.

12. The method of any one of claims 1-7, wherein after the part of pure nitrogen (123) at the first nitrogen product pressure is completely reheated in the main heat exchanger, part (125) of this part of pure nitrogen is output as a first nitrogen product, and the other part (126) is pressurized to a third nitrogen product pressure by means of the nitrogen booster (27) and output as a third nitrogen product.

13. An apparatus for producing nitrogen and oxygen by means of the cryogenic distillation of air, comprising:

(a) a first tower (11) working at a higher pressure and a second tower (13) working at a lower pressure, wherein the first tower and the second tower are brought into communication by means of heat exchange via a main condensing evaporator (12);
(b) at least one main air compressor (21), one air pre-cooling system (301), one air purification system (302), one air booster (22), a first expander booster (24), at least one main heat exchanger (1, 2), one nitrogen expander (23), at least one liquid expander (28), one liquid oxygen pump (31) and one supercooler (3);
(c) a pipeline for sending an air feed gas to the first tower (11) via the main air compressor (21), the air pre-cooling system (301), the air purification system (302) and the main heat exchanger (1);
(d) a pipeline for sending oxygen-enriched liquid air (110) at the bottom of the first tower (11) to the supercooler (3) for supercooling and to the second tower (13);
(e) a pipeline for sending pure liquid nitrogen (112) at the top of the first tower to the supercooler (3) for supercooling and to the upper part of the second tower;
(f) optionally, a pipeline for sending impure liquid nitrogen (111) in the middle part of the first tower to the supercooler (3) for supercooling and to the second tower;
(g) a pipeline for extracting impure nitrogen (121) from the second tower and sending the impure nitrogen to the supercooler (3) for warming and to the main heat exchanger (1, 2) for reheating;
(h) a pipeline for extracting pure liquid oxygen (122) from the main condensing evaporator (12) and sending the pure liquid oxygen to the liquid oxygen pump (31) for pressurization and then through the main heat exchanger (2); and
(i) a pipeline for extracting pure nitrogen (123) from the top of the first tower and sending the pure nitrogen to the main heat exchanger (1);

and further comprising a pipeline for sending a part of pure nitrogen (124), which has been reheated, from the main heat exchanger to the nitrogen expander (23), and returning the expanded pure nitrogen (124) to the main heat exchanger for reheating, wherein the nitrogen expander (23) is braked by means of the first expander booster (24), and the main air compressor (21), the air booster (22) and the first expander booster (24) are sequentially connected in series, and are connected to the main heat exchanger (2), the liquid expander (28) and then the first tower (11) via a pipeline.

14. The apparatus of claim 13, further comprising a pipeline for bringing the air booster (22) into communication with the main heat exchanger (2), and a pipeline that penetrates out from the middle part of the main heat exchanger (2) and connects the air expander (25) and the first tower (11) in sequence.

15. The apparatus of claim 14, wherein the nitrogen expander (25) is braked by means of a second expander booster (26), and the apparatus further comprises a pipeline for bringing the air booster (22) into communication with the second expander booster (26), and then sequentially connecting the main heat exchanger (2), the liquid expander (28) and the first tower (11).

16. The apparatus of claim 15, wherein the air booster (22) is directly connected to the second expander booster (26), or the air booster (22) is connected to the second expander booster (26) via the first expander booster (24).

17. The apparatus of any one of claims 13-16, wherein the main heat exchangers include a high pressure plate heat exchanger and a low pressure plate heat exchanger, or an integral combined heat exchanger.

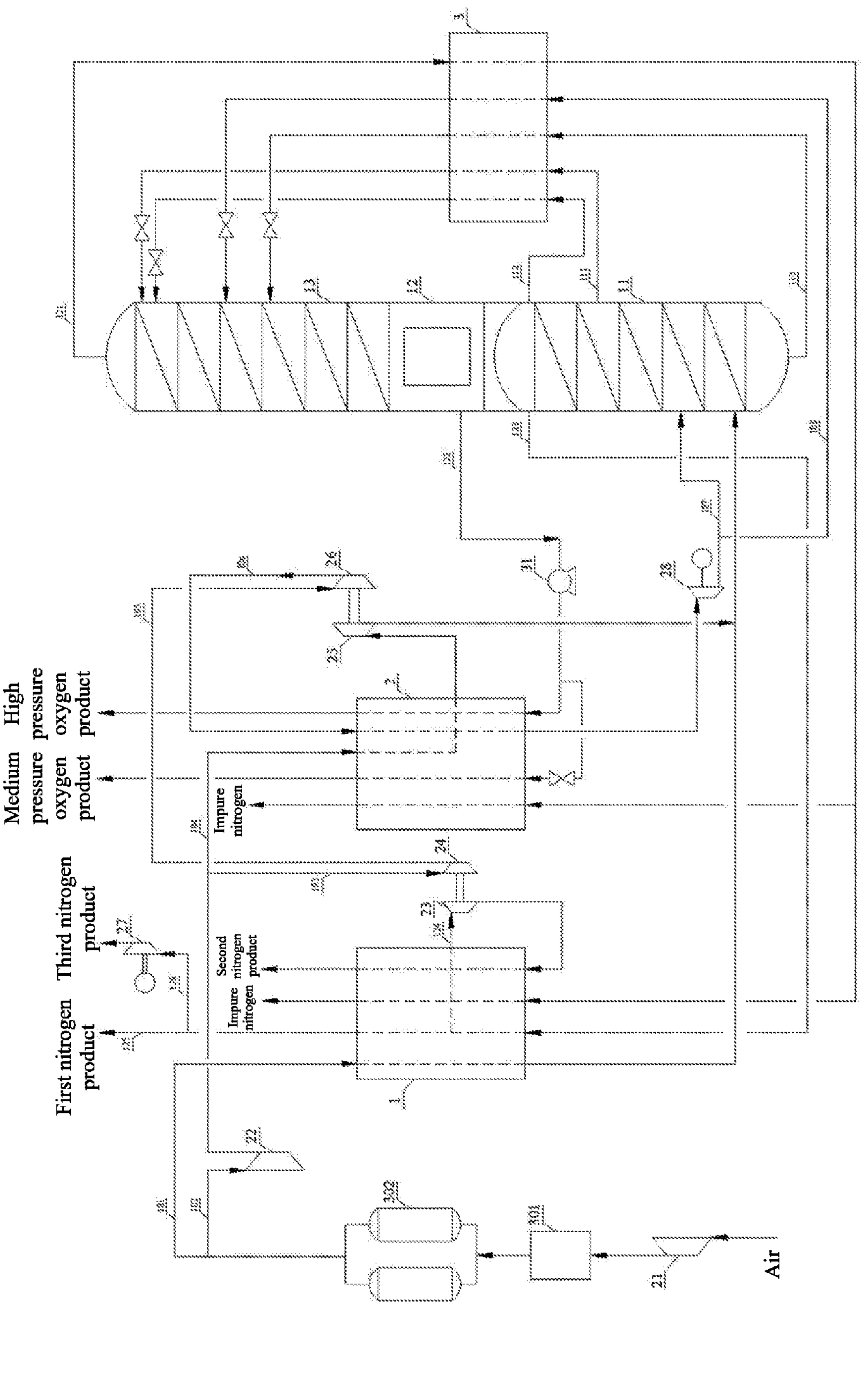
First nitrogen product
Third nitrogen product
Medium pressure oxygen product
High pressure oxygen product
Impure nitrogen
Second nitrogen product
Impure nitrogen
Air

Fig. 1

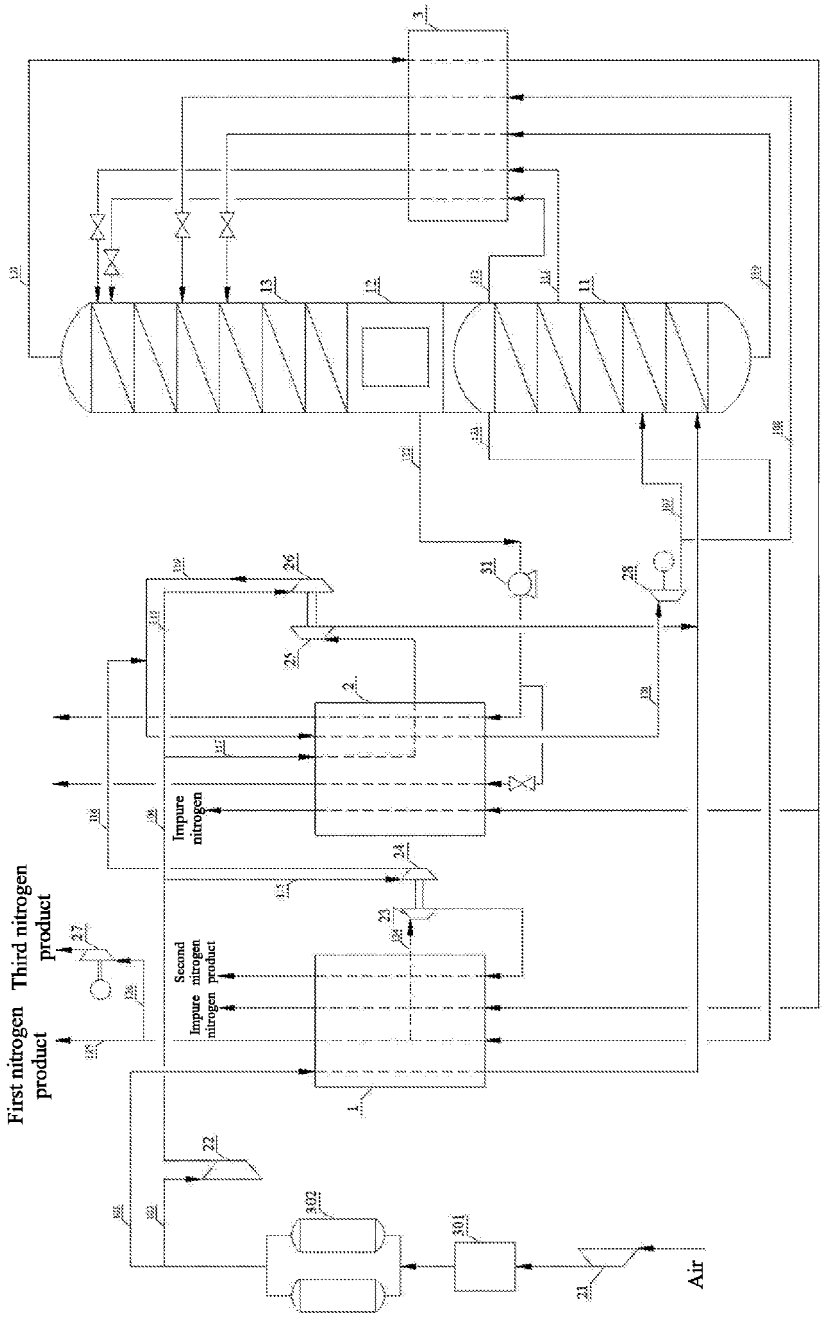
First nitrogen product
Third nitrogen product
Impure nitrogen
Second nitrogen product
Impure nitrogen
Air

Fig. 2

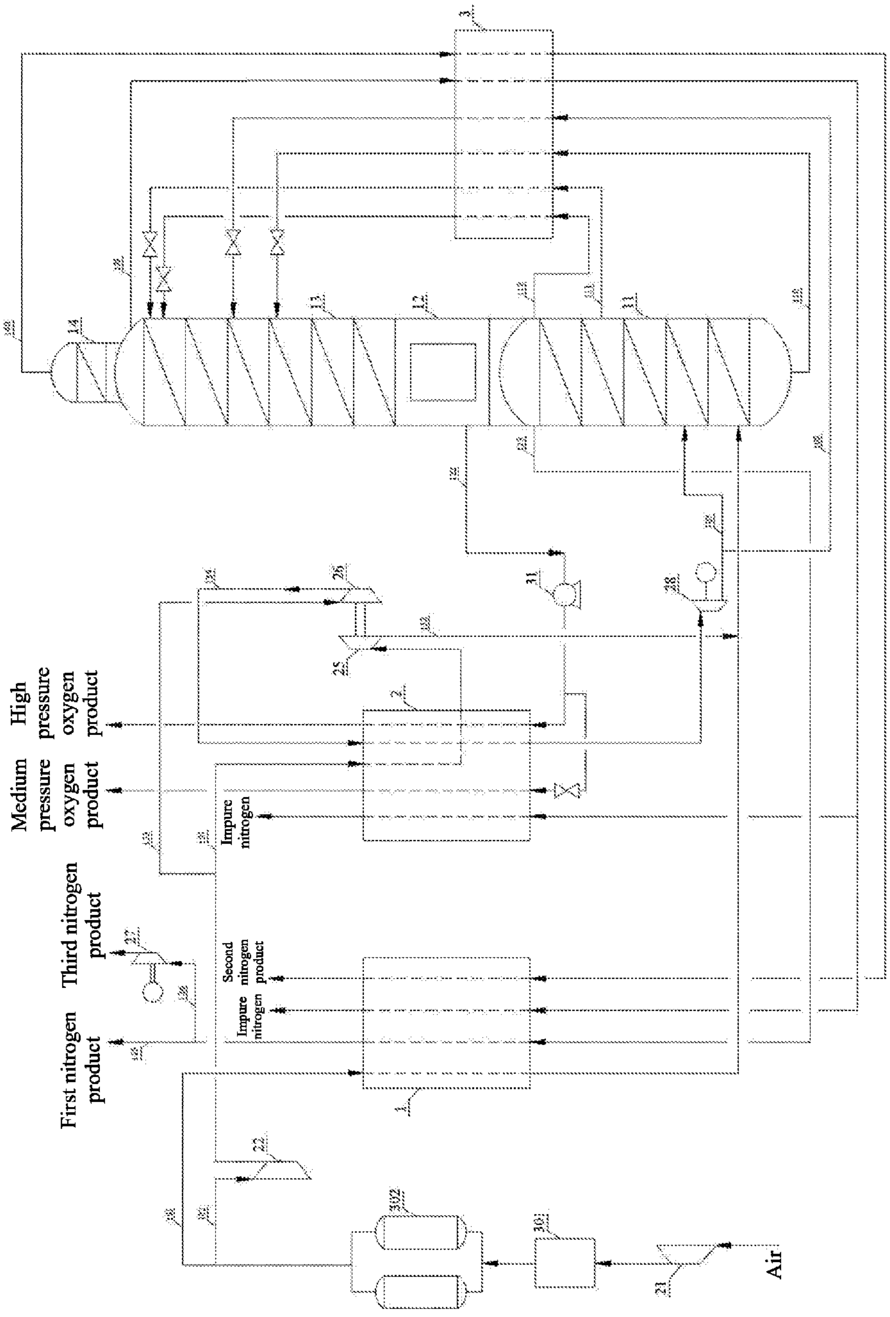
Air
First nitrogen product
Third nitrogen product
Medium pressure oxygen product
High pressure oxygen product
Impure nitrogen
Second nitrogen product

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2017/113525

A. CLASSIFICATION OF SUBJECT MATTER

F25J 3/04(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F25J3/04; F25J3/02; F25J3/00; CPC: F25J3/04412; F25J3/04309; F25J3/04345; F25J3/04393; F25J3/04351

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

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

CNABS, CNTXT, CNKI, VEN: 空分, 空气分离, 精馏, 增压机, 膨胀机, air, separation, separator, distillation, booster, expander, expansion, turbine

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	CN 103776240 B (ZHEJIANG HAITIAN GAS CO., LTD.) 06 July 2016 (2016-07-06) description, paragraphs 17-24, and figure 1	1-3, 9-13, 17
A	CN 201281522 Y (SUZHOU OXYGEN PLANT CO., LTD.) 29 July 2009 (2009-07-29) entire document	1-17
A	CN 1910419 A (L'AIR LIQUIDE SOCIETE ANONYME A DIRECTOIRE ET CONSEIL DE SURVEILLANCE POUR L'ETUDE ET L'EXPLOITATION DES PROCEDES GEORGES CLAUDE) 07 February 2007 (2007-02-07) entire document	1-17
A	CN 102706101 A (SUZHOU OXYGEN PLANT CO., LTD.) 03 October 2012 (2012-10-03) entire document	1-17
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☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 August 2018	**15 August 2018**

Name and mailing address of the ISA/CN	Authorized officer
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Facsimile No. **(86-10)62019451**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
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Form PCT/ISA/210 (patent family annex) (January 2015)