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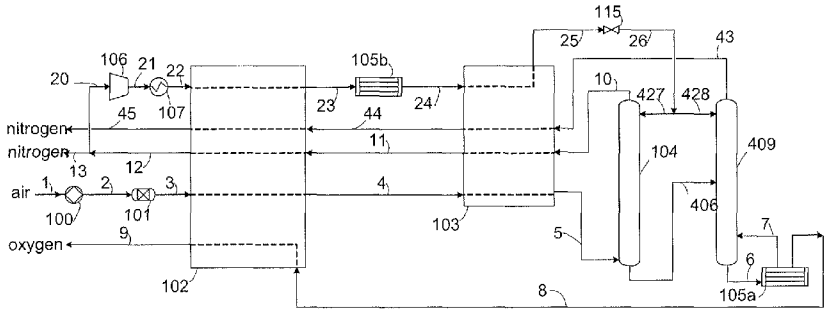

Fig. 3

(57) Abstract: An air separation process for the production of purified oxygen 9 from air 1 comprises: using a distillation column 104 to separate an incoming process stream 5; 211, 229 into a nitrogen stream 10 and an oxygen rich stream 6; 406, the distillation column 104 being at low pressure or at substantially ambient pressure; and using compression and cooling to provide a cold process stream 22, 23; 22, 23, 30, 31; 207, 208; 22, 23, 722, 723; 22, 23, 30, 31, 630, 631 for generating reflux 26; 35; 216; 26, 726 for the distillation column 104; wherein only a part of or none of the input process air 1 is compressed before distillation, with the remainder of the input process air 5; 229 being supplied to the distillation column 104 at low pressure or substantially ambient pressure; and wherein at least some of a nitrogen stream 10 produced by the distillation column 104 is rejected at substantially ambient pressure and temperature after heat exchange and without significant expansion or compression; such that during the air separation process a portion of the nitrogen in the incoming process air 1 that is not necessary for the production of oxygen of the desired purity does not undergo any significant compression.

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AIR SEPARATION

The present invention relates to a method and an apparatus for air separation, for example for the production of oxygen.

An air separation process separates atmospheric air into its primary components. Since nitrogen and oxygen are the major components, air separation processes are most often used to generate purified nitrogen and/or oxygen. In some cases the processes are designed to produce other gases such as argon, neon, krypton and xenon. Known air separation processes are commonly based on cryogenic distillation, and modern cryogenic distillation is based on processes initially developed by Dr. Carl von Linde in the late 19th and early 20th century.

The basic Linde air separation process involves compression and cooling of input process air with subsequent Joule-Thomson expansion to reduce the air to distillation pressures so that it can be separated in a distillation column. The air is generally taken from the atmosphere and it is cleaned or purified before the cryogenic process in order to remove water and carbon dioxide and other gases that could otherwise freeze in the low temperatures generated during the cryogenic process or pose an explosion hazard. Filters are used to remove dust and molecular sieves can be used to clean the air. The separated air gases can be supplied by pipeline to large industrial users adjacent to or nearby to the production plant or stored as liquid. For smaller volume users or where a pipeline delivery is not possible long distance transportation of the separated air components is generally done with the products in liquid form. Often, the end user's process will require a liquid product in any case.

Figure 1 shows a basic single column distillation process. The input process air will be compressed to a pressure typically between 5 and 10 bar and then cooled to ambient temperature to remove the heat generated by compression. Water cooling is often used. The compressed process air is then further cooled to its dew point against the output oxygen and nitrogen product streams. The cooled air is condensed by the boiling oxygen at the bottom of the distillation column and then expanded across a Joule-Thomson valve. The liquid air is distilled in the distillation column with the lower boiling point nitrogen being collected at the top of the column, and the higher boiling point oxygen being collected at the base of the column, after being warmed against the incoming air. Liquid oxygen "LOX" can be produced if sufficient refrigeration is provided for in the design.

In the single column design it may not be possible to obtain a nitrogen product with a high purity. Also, the oxygen recovery rate is rather low. The original "Linde air" was approximately 50% oxygen. In 1910, Linde developed the basis for a double-column distillation system, which is shown in Figure 2.

In the double–column distillation process, the key development is based on the use of a linked condenser/reboiler connecting two distillation columns. It will be appreciated that the two columns need not be arranged contiguously as shown in Figure 2. Instead, the columns just need to be connected together in a suitable fashion to enable the required fluid flow between them. Compressed and cooled process air is supplied to a first column for crude separation. The condenser/reboiler supplies liquid nitrogen "LIN" as reflux to cool the first column. A partly purified oxygen product is extracted from the bottom of the first column and after expansion this crude oxygen is released part way up the second column. In Figure 2 the left column is the first column and the right column is the second column. The oxygen separates to the bottom of the second column (lower pressure) and is boiled through the condenser/reboiler while the nitrogen from the top of the first column (higher pressure) is condensed. The condensing nitrogen provides heat to the base of the second column and the resultant LIN provides reflux for the first column and the second column. Pure oxygen can be extracted from the base of the second column and pure nitrogen from the top of the second column. In order to obtain the required minimum temperature difference (1~3 K), the first column should be operated at a higher pressure than the second column.

A thermodynamic analysis on Linde's double-column distillation system shows that the main irreversibilities are caused by the compression process of the air feed and the distillation processes. The specific power consumption for oxygen production (95 mole%) is around 5 times the theoretical minimum value (about 0.049 kWh/kg oxygen).

The Oxyton cycle was developed to reduce the irreversibilities of the distillation columns in Linde's double-column distillation system by the use of a third column. An alternative option is the use of an intermediate reboiler in the lower pressure column. The principle is to reduce the irreversibilities of the distillation column by distributed reboiling. The air feed (or a portion of the air feed) is compressed to a lower pressure (4~4.7 bar) than Linde's double-column distillation process. Such efforts have been developed further and implemented in the industry, and relevant discussion can be found in US 3327489, US 4704148 and US 6622520.

In 1946, Peter Leonidovitch Kapitza proposed a cycle in which the nitrogen is compressed at the cold end of the system and condensed against the boiling oxygen. This cycle is disclosed in GB 625107. Only one distillation column is used in this cycle. The possibility of using one or more intermediate reboilers is explored. The compressors are installed at the cold end of the system and are coupled to an expansion engine, as a result, the air feed has to be compressed to a pressure obviously above ambient pressure, and the nitrogen that is used for reflux has been compressed twice. The power consumption of this cycle is even larger than Linde's double-column distillation system.

In 1953, Manson Benedict developed a cycle to produce oxygen at relatively low pressure. This cycle is disclosed in US 2627731. The air feed is essentially uncompressed, i.e. it is not compressed to a pressure obviously above ambient pressure. Only one column is used to distil air. The operating pressure of the column is just above ambient pressure (for example, 1.2 bar at the top). An intermediate reboiler is placed in the distillation column. A portion of the nitrogen product is compressed and split. One portion of the split nitrogen is condensed in the intermediate reboiler. Another portion of the split nitrogen is further compressed, cooled to obviously below ambient temperature, and split into two streams (65% and 35%). The 65% nitrogen stream is condensed in the reboiler at the bottom of the distillation column, while the 35% nitrogen stream is expanded in an expander to a pressure similar to the operating pressure at the top of the distillation column. The expansion of nitrogen provides necessary refrigeration energy. In this cycle, the heat is not fully integrated in that: 1 the condensed nitrogen from the intermediate reboiler is not subcooled before expansion through a Joule-Thomson valve; 2 the amount of liquid nitrogen for reflux is not sufficient. The oxygen purity is 90% and the recovery rate is 96%. According to the values reported in US 2627731, there is no advantage in power consumption compared to Linde's double-column distillation system.

The idea of compressing a portion of the nitrogen product and condensing it as the reflux liquid for the distillation process has also be disclosed in US 4192662 and US 4464188. Various efforts have been made in improving the air separation unit by reducing the compression ratio in the main air compressor and recovering some power from the process by using a turbine during expansion. Efforts have also been made to improve efficiencies by reducing the power input required for compression by reducing the temperature of compression of the feed air or by attempts to avoid compression of the feed air altogether. However, potential still remains for further improvements in the efficiency of the process since practical efficiencies are still some distance away from the theoretical efficiency.

Viewed from a first aspect the invention provides an air separation process for the production of purified oxygen from air, the process comprising: using a distillation column to separate an incoming process stream into a nitrogen stream and an oxygen rich stream, the distillation column being at low pressure or at substantially ambient pressure; wherein only a part of or none of the input process air is compressed before distillation, with the remainder of the input process air being supplied to the distillation column at low pressure or substantially ambient pressure; and wherein at least some of a nitrogen stream produced by the distillation column is rejected at substantially ambient pressure and temperature after heat exchange and without significant expansion or compression; such that during the air separation process a portion of the nitrogen in the incoming process air that is not necessary for the production of oxygen of the desired purity does not undergo any significant compression.

The present inventors have found that undesirable power consumption in the prior art processes is mainly caused by the compression of air feed in Linde's double-column distillation system, and by the compression of nitrogen in the cycle disclosed in US 2627731. In relation to this, the inventors have made the non-obvious realisation that with prior art air separation processes there is in effect a nitrogen excess when the aim is the production of purified oxygen. Having determined that this issue exists, the invention then seeks to address the newly identified problem of how to improve the efficacy of an air separation process by taking advantage of the excess in nitrogen.

With the new process defined above, one advantage arises because not all of the input process air is compressed, or none of the input process air is compressed. This means that power is not wasted in compression of the excess nitrogen and in some embodiments, in unnecessary compression of oxygen in the air feed. Also, and in synergistic combination with this feature, at least a part of the nitrogen produced in the ambient pressure distillation is rejected without compression or expansion. Once again, this ensures that no power is wasted in compression of excess nitrogen. Also, it is easier to distil air at lower pressure since the relative volatility between the nitrogen and the oxygen is larger. The construction of the distillation column is also simplified when it does not need to act as a pressure container.

A cold process stream formed by compression and cooling may be used directly as reflux, optionally after condensing. Alternatively, a cold process stream formed by compression and cooling may be used as feed gas for a further distillation column, with a nitrogen product of this distillation column being used as reflux for the low pressure distillation column, optionally after condensing.

It should be noted that the reference to low pressure and/or substantially ambient pressure does not mean that there is no compression at all of all or part of the input process air and it does not mean that the distillation column operates without any internal pressure. Similarly, the reference to an absence of significant compression for the 'excess' nitrogen does not mean that this excess nitrogen undergoes zero compression. Clearly, it may be necessary to introduce some small pressure increase by the use of fans or blowers to transport the process streams. As a result, some small compression may occur as the input process air is conveyed to other parts of the system. Hence, the preferred arrangements do not exclude and in fact may include small increases in pressure arising from air movement and the use of pumping devices or fans to move the air and separated streams through the air separation process. Furthermore, it is preferred for the operating pressure to be slightly above ambient since this prevents incursion of outside air into the air separation unit and also permits extraction of the resultant gases from the system.

The low pressure may be a pressure of below 10 bar, preferably below 5 bar, and more preferably below 2 bar, for example about 1.5 bar. The pressure may be close to

ambient pressure, for example it may be a substantially ambient pressure and a pressure of between 1.01 bar and 1.7 bar. The process streams that are not significantly compressed may also have pressures of below 10 bar, preferably below 5 bar, and more preferably below 2 bar, for example about 1.5 bar. In some preferred embodiments this pressure may be a substantially ambient pressure of between 1.01 bar and 1.7 bar. The pressures referenced herein are absolute pressures.

Preferably, the process air is filtered in order to remove dust and also cleaned/purified in order to remove water and carbon dioxide as well as other parts of the atmospheric air that could otherwise freeze during the cryogenic process or pose an explosion hazard.

Preferably, the process air is cooled to a temperature of several degrees below the cooling water temperature in a direct contact aftercooler prior to the removal of impurities.

The process may include compression and cooling of a part of the nitrogen stream produced by the distillation column in order to provide some or all of a cold process stream for use as reflux. The nitrogen stream from the distillation column may be used for heat exchange to cool incoming process air prior to the compression and cooling.

Preferably, the process includes compression and cooling of a portion of the nitrogen stream produced by the distillation column followed by expansion at ambient temperature or subambient temperature after being cooled by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation to enable further heat exchange to cool incoming process air.

In preferred embodiments one or more multi-stream heat exchanger(s) are used for cooling of the input process air and/or of a nitrogen stream used for reflux and/or of a nitrogen stream to be expanded, the cooling occurring by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation.

Preferably, said at least a part of the nitrogen stream that is compressed and cooled for reflux is condensed and supplied to the distillation column as liquid nitrogen.

The purified oxygen may be the product of the distillation column. The process preferably incorporates a step of reboiling of the oxygen stream produced by the distillation column, whereby an oxygen stream is returned to the column and another oxygen stream is available to form the output of the process. In preferred embodiments the reboiling step is performed by a combined condenser/reboiler wherein the nitrogen stream for reflux is condensed by reboiling of the oxygen stream produced by the distillation column.

In one preferred embodiment, none of the input process air is significantly compressed and the required cooling is achieved by compression and cooling of a part of one or more nitrogen streams obtained after separation by distillation. Thus, the process may comprise providing input process air to the distillation column without significant compression, or without

any compression. The input process air is preferably passed to the distillation column without compression being applied by a compressor.

By moving the nitrogen compression step after the step of separation in the distillation column efficiency gains can be made since there is no requirement for compression of the entire desired amount of the air feed. The bulk of the compression work is applied after separation and only the nitrogen is compressed. This provides a consequent reduction in the mass flow through the compressor and in turn this gives rise to considerable efficiency improvements. In Linde's double-column distillation system, generally the air feed has to be compressed to 5~6 bar to enter the higher pressure column. At this pressure level, the nitrogen vapour can be condensed by the boiling oxygen to provide the reflux liquid. There is additional nitrogen available from the higher pressure column. Since this process does not require a similar compression of the oxygen, then viable air separation processes will result when only some nitrogen is compressed and/or not all of the air feed is compressed. This provides a consequent reduction in the mass flow through the compressor and in turn this gives rise to considerable efficiency improvements.

In one preferred arrangement the nitrogen stream produced by the distillation column is split into at least two parts, with a first part being expelled to atmosphere at substantially ambient temperature and pressure after heat exchange with incoming process air, and a second part being compressed and cooled before heat exchange with other process streams and then subsequently condensed, expanded and used as the reflux for the distillation column. When the nitrogen stream is split into two parts the first part may be between 40% and 60% of the total volume, preferably about 50% and the second part may be between 60% and 40% of the total volume, preferably about 50%. The nitrogen stream is preferably split into parts after heat exchange with incoming process air.

After the compression and cooling the second part may be cooled by heat exchange with the output oxygen and nitrogen product streams from the distillation column. The second part is preferably condensed in a condenser/reboiler that includes the condenser of the distillation column. After the condenser the second part may be cooled by heat exchange with the nitrogen stream exiting the distillation column and then expanded before being used as reflux in the distillation column.

The nitrogen stream produced by the distillation column may be split into at least three parts, with first and second parts as discussed above and the third part being used in a compression, cooling and expansion cycle to produce further cold for heat exchange with the incoming process air. After heat exchange, the third part may be expelled to atmosphere at substantially ambient temperature and pressure.

When the stream is split into three parts, the first part may be between 30% and 60% of the total volume, the second part may be between 60% and 30% of the total volume and

the third part may be between 1% and 20% of the total volume, or optionally between 1% and 15% of the total volume. In a preferred arrangement, the split is set at a ratio of about 40% : 48% : 12% for the first, second and third parts, i.e. with about half the nitrogen being expelled to atmosphere and half being used for extra cooling and reflux. The amount of the third part is preferably increased to up to 20% if a larger temperature difference is required, and the increase may be at the expense of a reduction in the first part. In an alternative preferred arrangement the split may be set at a ratio of about 50% : 48% : 2% for the first, second and third parts. Once again the amount of the third part may be increased if a larger temperature difference is required, for example to up to 20%.

The distillation column may be equipped with two reboilers. A first reboiler may receive the oxygen stream from the distillation column as discussed above. This first reboiler may be used to produce the output purified oxygen. A second reboiler may be placed part way up the distillation column, preferably below the feed stage of the incoming air stream, for example one to ten chemical equilibrium stages below the feed stage, preferably one to five equilibrium stages below the feed stage. The first reboiler may be part of a combined condenser/reboiler that is used to condense a compressed part of the nitrogen stream, preferably this is a second part of the nitrogen stream as discussed above. The second reboiler may be a part of a combined condenser/reboiler that is used to condense a compressed part of the nitrogen stream. The part of the nitrogen stream that is condensed in the second condenser/reboiler may be a further part of the nitrogen stream that is split from the stream and processed in a similar manner to the second part discussed above.

The process with two reboilers may also include a third part of the nitrogen stream used to produce further cold as discussed above. Hence, with two reboilers the nitrogen stream produced by the distillation column may be split into at least four parts after heat exchange with other process streams. The first, second and third parts may be as discussed above with the second part being condensed in the first condenser/reboiler that receives the oxygen rich stream from the base of the distillation column, and the fourth part is a further part similar to the second part that is condensed in the second condenser/reboiler where the reboiler is placed mid-way up the distillation column.

The fourth part may be obtained by taking a portion of the second part thereby splitting it into two streams, for example at a ratio of reduced second part : fourth part of between 55% : 45% and 75% : 25%, preferably about 67% : 33%.

Where two condenser/reboilers are used the nitrogen from the two condensers may be expanded and combined before being used as reflux for the distillation column.

Some preferred embodiments may utilise multiple distillation columns.

The multiple distillation columns may include first and second distillation columns, one or both of which are operated at low pressure, preferably at substantially ambient pressure.

With this arrangement, the process may comprise providing input process air to a first distillation column in which the air is separated into a nitrogen stream and an oxygen rich stream; sending the oxygen rich stream to a second distillation column; compressing and cooling at least a part of the nitrogen stream from the first distillation column; using the compressed and cooled nitrogen as reflux for at least one of the first distillation column and the second distillation column; and further separating the oxygen rich stream in the second distillation column.

In some preferred embodiments, both of the distillation columns are operated at similar low pressure to the pressure of the input process air.

The process may include rejecting at least some of the nitrogen stream from the second distillation column at ambient temperature after heat exchange and without expansion or compression.

In a preferred embodiment the input process air is cooled to distillation temperature by heat exchange with at least a part of a nitrogen stream from the second distillation column and/or at least a part of an oxygen stream from the second distillation column. In this way, cold energy can be recovered from the product stream(s). The input process air may be cooled by heat exchange with at least a part of the nitrogen stream from the first distillation column.

Preferably only a part of the nitrogen stream from the first distillation column is compressed and cooled. It has been found that there is no need to use the entirety of the nitrogen stream from the first distillation column as reflux and hence efficiency can be improved by separating some of the nitrogen stream prior to compression. In a preferred embodiment further cooling duty is provided by compression, cooling and expansion of a part of the separated nitrogen. Excess nitrogen, which is not required to generate cooling for the air separation process, can be utilised as a product or vented to atmosphere.

In one arrangement, since not all the nitrogen produced by the first distillation column is needed for later cooling one part of the nitrogen may be separated and used for cooling the input process air, with the other part passing to the compression and cooling step. In a preferred arrangement, all of the nitrogen stream from the first distillation column is heated by heat exchange before separation of the nitrogen stream and thus all the nitrogen stream from the first distillation column is preferably used to cool other gas streams such as the incoming process air.

Said at least a part of the nitrogen stream that is compressed and cooled for reflux may be cooled by heat exchange with at least a part of a nitrogen stream from the second distillation column and/or at least a part of an oxygen stream from the second distillation column. The nitrogen is preferably compressed before this cooling step. It is preferred to use an outside coolant to cool the nitrogen after compression, with further cooling from the heat

exchange with other process streams occurring subsequently. Water may be used as the outside coolant. In a preferred embodiment the nitrogen is compressed to over 4 bar, preferably about 4.9 bar and then cooled to about 283 K, or lower if lower temperature coolant is available.

Preferably, said at least a part of the nitrogen stream that is compressed and cooled for reflux is condensed and supplied to one or both distillation columns as liquid nitrogen.

The compressed and cooled nitrogen is advantageously supplied as reflux for both of the distillation columns in preferred embodiments.

The process preferably incorporates a step of reboiling of the oxygen stream produced by the second distillation column. In preferred embodiments this step is performed by a combined condenser/reboiler wherein the nitrogen stream for reflux is condensed by reboiling of the oxygen stream produced by the second distillation column.

In an alternative preferred arrangement a part of the incoming process air is compressed and cooled and used to produce reflux for distillation and separation of air. Another part of the incoming process air is conveyed to the distillation column at low pressure or substantially ambient pressure. The nitrogen stream produced by the distillation column may be expelled to atmosphere at ambient pressure and temperature after heat exchange with other process streams, for example the incoming process air.

With this arrangement it is preferred to use multiple distillation columns. The distillation column at low pressure or substantially ambient pressure is a first column and it receives the part of the incoming process air that is not significantly compressed along with reflux generated from the incoming process air that is subject to compression and cooling. A second distillation column is preferably operated under pressure and receives compressed and cooled input process air as a feed gas. Preferably, the oxygen rich stream from the second distillation column is used, after expansion, as a further feed for the first distillation column. The feed stage for this oxygen rich stream may be one to five equilibrium stages above the feed stage for the unseparated incoming process air. Nitrogen produced by the second distillation column may be used as reflux for the first distillation column and/or as reflux for the second distillation column.

Preferably, the oxygen rich output stream of the first distillation column is reboiled. The purified oxygen stream that is the product of the process may be produced by the reboiler. The reboiler may be a combined condenser/reboiler also used for condensing the nitrogen output from the second distillation column. After condensing this nitrogen may be used as reflux for the second distillation column and/or expanded and used as reflux for the first distillation column. The nitrogen stream supplied from the second distillation column as reflux for the first distillation column may be cooled by heat exchange with the waste nitrogen produced by the first distillation column.

In a preferred process of this type, the input process air is split into parts, of which a first part is passed to the first distillation column without significant compression and a second part is compressed and cooled and used as the feed gas for the second distillation column. Preferably, the compressed and cooled input process air is further split into parts, being the second part above and a third part, which is further cooled and expanded before being recombined with the first part and used as feed gas for the first distillation column.

With this split, to produce the first part and the part for compression and cooling the input process air may be split in a ratio of first part : part for compression of between 35% : 65% and 1% : 99% by volume, with the first part being about 25% by volume in one preferred embodiment. The part for compression may be split in a ratio of second part : third part of between 85% : 15% and 100% : 0% by volume, with the second part being about 98% in one preferred embodiment.

Viewed from a second aspect the invention provides an air separation apparatus for the production of purified oxygen from air, the apparatus comprising: a distillation column arranged to separate an incoming process stream into a nitrogen stream and an oxygen rich stream, the distillation column being at low pressure or at substantially ambient pressure; wherein only a part of or none of the input process air is compressed before distillation, with the remainder of the input process air being supplied to the distillation column at low pressure or substantially ambient pressure; and wherein at least some of a nitrogen stream produced by the distillation column is rejected at substantially ambient pressure and temperature after heat exchange and without significant expansion or compression; such that during the air separation process a portion of the nitrogen in the incoming process air that is not necessary for the production of oxygen of the desired purity does not undergo any significant compression.

The pressures used may be as described above in connection with the process of the first aspect.

A cold process stream formed by a compression and cooling cycle may be used directly as reflux, optionally after condensing.

Alternatively, a cold process stream formed by a compression and cooling cycle may be used as feed gas for a further distillation column, with a nitrogen product of this distillation column being used as reflux for the low pressure distillation column, optionally after condensing.

Preferably, the apparatus includes filters and/or a cleaning/purifying unit in order to remove dust, water, carbon dioxide and/or other parts of the atmospheric air that could otherwise freeze or pose an explosion hazard during the cryogenic process.

Preferably, the apparatus includes direct contact aftercoolers in order to cool the process air to a temperature of several degrees below the cooling water prior to the removal of impurities.

Preferably, the distillation column uses trays or structured packing.

The apparatus may comprise a compression and cooling cycle for compression and cooling of a part of the nitrogen stream produced by the distillation column in order to provide some or all of the cold process stream for use as reflux. The nitrogen stream from the distillation column may be passed through a heat exchanger to cool incoming process air prior to the compression and cooling.

Preferably, the apparatus includes a compression and cooling cycle for compression and cooling of a portion of the nitrogen stream produced by the distillation column followed by an expander for expansion of this portion of the nitrogen stream at ambient temperature or subambient temperature after being cooled by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation to enable further heat exchange to cool incoming process air.

The apparatus may include one or more multi-stream heat exchanger(s) for cooling of the input process air and/or of a nitrogen stream used for reflux and/or of a nitrogen stream to be expanded by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation.

Preferably, said at least a part of the nitrogen stream that is compressed and cooled for reflux is condensed and supplied to the distillation column as liquid nitrogen.

The purified oxygen may be the product of the distillation column. The apparatus may include an outlet for withdrawing the purified oxygen, and/or a storage tank for storing the purified oxygen for future withdrawal and use by the consumer.

The apparatus preferably incorporates a reboiler for reboiling of the oxygen stream produced by the distillation column, whereby an oxygen stream is returned to the column and an oxygen stream is available to form the output of the apparatus. In preferred embodiments the reboiler is in a combined condenser/reboiler wherein the condenser is for condensing the nitrogen stream for reflux during reboiling of the oxygen stream produced by the distillation column.

In one preferred embodiment, none of the input process air is significantly compressed and the required cooling is achieved by compression and cooling of a part of one or more nitrogen streams or nitrogen rich streams obtained after separation by distillation. Thus, the apparatus may be arranged to provide input process air to the distillation column without significant compression, or without any compression. The input process air is preferably passed to the distillation column without compression being applied by a compressor.

In one preferred arrangement the nitrogen stream produced by the distillation column is split into at least two parts, with a first part being expelled to atmosphere at substantially ambient temperature and pressure after passing through a heat exchanger for heat exchange with incoming process air, and a second part being passed to a compression and cooling cycle before heat exchange in a heat exchanger with other process streams and then subsequently condensed, expanded in a Joule-Thomson valve and used as the reflux for the distillation column. When the nitrogen stream is split into two parts the first part may be between 40% and 60% of the total volume, preferably about 50% and the second part may be between 60% and 40% of the total volume, preferably about 50%. The nitrogen stream is preferably split into parts after heat exchange with incoming process air.

After the compression and cooling cycle the second part may be passed through a heat exchanger for heat exchange with the output oxygen and nitrogen product streams from the distillation column. The second part is preferably condensed in a condenser/reboiler that includes the condenser of the distillation column. After the condenser the second part may be cooled by heat exchange with the nitrogen stream exiting the distillation column and then expanded before being used as reflux in the distillation column.

The nitrogen stream produced by the distillation column may be split into at least three parts, with first and second parts as discussed above and the third part being used in a compression, cooling and expansion cycle to produce further cold for heat exchange with the incoming process air. After heat exchange, the third part may be expelled to atmosphere at substantially ambient temperature and pressure.

When the stream is split into three parts, the parts may have volumes and ratios as discussed above in relation to the process.

The distillation column may be equipped with two reboilers. A first reboiler may receive the oxygen stream from the distillation column as discussed above. This first reboiler may be used to produce the output purified oxygen. A second reboiler may be placed part way up the distillation column, preferably below the feed stage of the incoming air stream, for example one to ten chemical equilibrium stages below the feed stage, preferably one to five equilibrium stages below the feed stage. The first reboiler may be part of a combined condenser/reboiler that is used to condense a compressed part of the nitrogen stream, preferably this is a second part of the nitrogen stream as discussed above. The second reboiler may be a part of a combined condenser/reboiler that is used to condense a compressed part of the nitrogen stream. The part of the nitrogen stream that is condensed in the second condenser/reboiler may be a further part of the nitrogen stream that is split from the stream and processed in a similar manner to the second part discussed above.

The process with two reboilers may include a third part of the nitrogen stream used to produce further cold as discussed above. Hence, with two reboilers the apparatus may be

arranged to split nitrogen stream produced by the distillation column into at least four parts after heat exchange with other process streams, the parts being as discussed above in relation to the corresponding process.

Where two condenser/reboilers are used the nitrogen from the two condensers may be expanded and combined before being used as reflux for the distillation column.

Some preferred embodiments utilise multiple distillation columns.

The multiple distillation columns may include first and second distillation columns, one or both of which are operated at low pressure, preferably at substantially ambient pressure. In a preferred embodiment the apparatus comprises: a first distillation column for separating input process air into a nitrogen stream and an oxygen rich stream; a second distillation column for receiving the oxygen rich stream and further separating it; a compressor and a cooler for compressing and cooling at least a part of the nitrogen stream from the first distillation column; wherein the apparatus is arranged such that the compressed and cooled nitrogen is supplied as reflux for at least one of the first distillation column and the second distillation column.

Preferably the input process air at the first distillation column has not undergone significant compression. In a preferred embodiment the apparatus includes an input air path for supplying process air from the atmosphere and there is no compressor in the input air path. The input process air may be at a pressure as described above.

Preferably, both of the distillation columns are operated at similar pressure to the pressure of the input process air.

The apparatus may be arranged to reject at least some of the nitrogen stream from the second distillation column at ambient temperature after heat exchange and without expansion or compression.

A preferred embodiment of the apparatus comprises one or more heat exchanger(s) for cooling of the input process air to distillation temperature. The heat exchanger(s) may be fluidly connected within the apparatus for heat exchange between the input process air and at least a part of a nitrogen stream from the second distillation column and/or with at least a part of an oxygen stream from the second distillation column. The heat exchanger(s) may be fluidly connected within the apparatus for heat exchange with some or all of the nitrogen stream from the first distillation column.

The apparatus is preferably arranged to divide the nitrogen stream from the first distillation column such that only a part of this nitrogen stream is compressed and cooled for use as reflux. Further cooling duty may be provided by compression, cooling and expansion of a part of the remaining nitrogen.

In a preferred arrangement, all of the nitrogen product from the first distillation column is heated via the heat exchanger(s) before separation of this nitrogen stream into waste nitrogen and nitrogen for reflux or further cooling.

Said at least a part of the nitrogen stream that is compressed and cooled for reflux may be cooled by one or more heat exchanger(s) via heat exchange with at least a part of a nitrogen stream from the second distillation column and/or with at least a part of an oxygen stream from the second distillation column. The nitrogen is preferably compressed by the compressor before this cooling step. It is preferred to use an outside coolant to cool the nitrogen after compression and hence the air separation unit preferably comprises a heat exchanger and a supply of outside coolant for removal of compression heat from the compressed nitrogen. Water cooling may be used as the outside coolant. In a preferred embodiment the nitrogen is compressed to over 4 bar, preferably about 4.9 bar and then cooled to about 283 K, or lower if lower temperature coolant is available.

In preferred embodiments one or more multi-stream heat exchanger(s) are used as the one or more heat exchanger(s). The same multi-stream heat exchangers may be used for cooling of the input process air and the nitrogen for reflux.

Preferably, the apparatus comprises a condenser for condensing at least a part of the nitrogen stream after it is compressed and cooled.

The compressed and cooled nitrogen is advantageously supplied as reflux for both of the distillation columns in preferred embodiments.

The apparatus preferably comprises a reboiler for reboiling of the oxygen stream produced by the second distillation column. In preferred embodiments this comprises a combined condenser/reboiler wherein the nitrogen stream for reflux is condensed by reboiling of the oxygen stream produced by the second distillation column.

In an alternative preferred arrangement the apparatus comprises a compression and cooling cycle for compressing and cooling a part of the incoming process air to enable it to be used to generate reflux for distillation and separation of air. With this apparatus, another part of the incoming process air is conveyed to the distillation column at low pressure or substantially ambient pressure. The nitrogen stream produced by the distillation column may be expelled to atmosphere at ambient pressure and temperature after heat exchange with other process streams, for example the incoming process air.

With this arrangement it is preferred to use multiple distillation columns. The distillation column at low pressure or substantially ambient pressure is a first column and it receives the part of the incoming process air that is not significantly compressed along with reflux generated from the incoming process air that is subject to compression and cooling. A second distillation column is preferably operated under pressure and receives compressed and cooled input process air as a feed gas. Preferably, the oxygen rich stream from the

second distillation column is used, after expansion, as a further feed for the first distillation column. The feed stage for this oxygen rich stream may be one to five equilibrium stages above the feed stage for the unseparated incoming process air. Nitrogen produced by the second distillation column may be used as reflux for the first distillation column and/or as reflux for the second distillation column.

Preferably, the apparatus includes a reboiler for reboiling the oxygen rich output stream of the first distillation column. The purified oxygen stream that is the product of the apparatus may be produced by the reboiler. The reboiler may be a combined condenser/reboiler also used for condensing the nitrogen output from the second distillation column. After condensing this nitrogen may be used as reflux for the second distillation column and/or expanded and used as reflux for the first distillation column. The nitrogen stream supplied from the second distillation column as reflux for the first distillation column may be cooled by heat exchange with the waste nitrogen produced by the first distillation column.

In a preferred apparatus of this type, the input process air is split into parts, of which a first part is passed to the first distillation column without significant compression and a second part is compressed and cooled and used as the feed gas for the second distillation column. Preferably, the compressed and cooled input process air is further split into parts, being the second part above and a third part, which is further cooled and expanded before being recombined with the first part and used as feed gas for the first distillation column.

The apparatus may be arranged to split the incoming process air in ratios as discussed above in relation to the corresponding process.

Preferred embodiments of the present invention will now be described by way of example only and with reference to the accompanying drawings in which:

Figure 1 shows a basic Linde single column air separation process;

Figure 2 shows a Linde double column process;

Figure 3 illustrates an embodiment of an air separation system using multiple distillation columns;

Figure 4 shows an alternative embodiment that uses a single distillation column;

Figure 5 is a modification to the embodiment of Figure 4 using a dual-reboiler cycle;

Figure 6 illustrates a further alternative embodiment of an air separation system;

Figure 7 illustrates another alternative modification of the system of Figure 4 using a dual-reboiler cycle;

Figure 8 shows a modification of the system of Figure 5 using three reboilers;

Figure 9 shows a modification to the cycle of Figure 7;

Figure 10 illustrates a scheme for removal of impurities by use of a reversing heat exchanger;

Figure 11 shows a modified cycle incorporating the use of such a reversing heat exchanger;

Figure 12 shows a further example of a modified cycle using a combination of a purification unit and reversing heat exchanger for the removal of impurities;

Figure 13 shows the mass balance for the system of Figure 4; and

Figure 14 shows the mass balance for the system of Figure 6.

As set out above, the present processes are based on the realisation that not all the nitrogen in the incoming air needs to be used in compression and cooling for the production of purified oxygen. The embodiments described herein illustrate ways in which increases in efficiency can be obtained by avoiding the use of power in compression of the unnecessary nitrogen and oxygen. In some embodiments, these efficiency increases are achieved in part by cold compression of the nitrogen after crude oxygen has been removed. Some prior art improvements have focused on achieving efficiency gains by reducing the compression ratio in the mistaken belief that all the air must be compressed. However, as explained below the mass flow rate can be more important than compression ratio in relation to energy usage.

For an adiabatic compression process, if ideal gas is compressed, the power consumed can be expressed as:

$$W = \frac{W_{ideal}}{\eta_s} = \frac{1}{\eta_s}\dot{m}(h_{out} - h_{in}) = \frac{1}{\eta_s}\dot{m}c_p(T_{out} - T_{in}) = \frac{1}{\eta_s}\dot{m}c_pT_{in}((\frac{p_{out}}{p_{in}})^{\frac{\gamma-1}{\gamma}} - 1)$$

Where η_s is the isentropic efficiency, $\dot{m}$ is the mass flow rate, c_p is the specific heat at constant pressure, T_{in} and T_{out} are the inlet and outlet temperatures, p_{in} and p_{out} are the inlet and outlet pressures, h_{in} and h_{out} are the inlet and outlet specific enthalpies and γ is the ratio of specific heats.

From this equation it is seen that the power consumed in a compressor varies with both the compression ratio and the mass flow rate. Clearly, the compression work will vary linearly with the mass flow rate. By way of contrast the relationship between power consumption and compression ratio is not linear. Since the index $(\gamma-1)/\gamma$ is smaller than one, the mass flow rate is more important than the compression ratio for the power reduction.

An embodiment of a process with reduced compression mass flow is shown in Figure 3. The air 1, after cooling and impurities removal from streams 2 and 3, is cooled down to its dew point at stream 5 and sent to the first distillation column 104. The air is not significantly compressed aside from a small increase in pressure arising when it is compressed by a blower 100 through the cooling and purifying process. The operating pressure at the top of column 104 is around 1.2 bar (absolute pressure is used herein). The first distillation column 104 separates the air into nitrogen and partially purified oxygen. The crude partially purified oxygen 406 is sent to the second distillation column 409 for further separation. The nitrogen 10 from the top of the first distillation column 104 is heated to 283 K by heat

exchangers 102 and 103 and compressed to 4.9 bar by a compressor 106. A part of the nitrogen 13 is extracted after heating and before the compression since there is no need to use all the nitrogen as reflux. Thus, only a part of the nitrogen 20 is compressed. This reduces the power that is required for compression. The compressed nitrogen 21 is cooled to 283 K by a further heat exchanger 107 to produce stream 22, for example using water cooling and waste nitrogen 45. The nitrogen can optionally be cooled to lower temperatures if lower temperature sources are available. After further cooling down to the dew point at stream 23 the nitrogen stream is condensed in a condenser 105b, subcooled in a heat exchanger 103, expanded in a Joule-Thomson valve 115 and then split into two streams of LIN 427 and 428.

The two LIN streams 427 and 428 are used as the reflux in the first and second distillation columns. The second distillation column 409 is used to produce the final oxygen product via output stream 6, taken from the base of the column and further treated as explained below. The second column 109 will also produce nitrogen via output stream 43. After heat exchange this nitrogen is expelled from the process at ambient temperature and pressure as stream 45. The operating pressure at the top of column 409 is also around 1.2 bar.

The oxygen stream 6 from the base of the second column 409 is passed through the reboiler 105a, which is linked with the nitrogen condenser 105b in a combined condenser/reboiler. Some of the oxygen stream 7 is returned to the second distillation column 409. The remainder 8 is warmed by heat exchanger 102 and becomes the output oxygen product 9.

The purity of the oxygen product 9 can be above 95% and the oxygen recovery rate is close to 100%. The temperature difference in the linked condenser/reboiler is 1.2 K in this case.

An alternative process (not shown) based on the process of Figure 3 involves applying a nitrogen expansion process to a portion of the nitrogen stream 13 that is extracted before compression, and this expansion process is used to produce further cooling duty. In this process, a portion of the extracted nitrogen is compressed to 4.5 bar and cooled by cooling water. The nitrogen is then expanded in an expander to produce the cold energy. The temperature difference of the linked condenser/reboiler is kept to be 1.2 K. The minimum approach temperature difference in multi-stream heat exchangers is also about 1.2 K. This process can be both practical and feasible as an industrial process. The pinch point locates above the temperature of the condenser. The pinch position can be adjusted by adjusting the compression ratio of the nitrogen compressor. The required temperature difference can be adjusted by adjusting the amount of the expanded nitrogen.

One possible alternative process derived from the process shown in Figure 3 is that the nitrogen product 43 from the second column 109 can be mixed with the nitrogen product

10 from the first column 104 before being heated to ambient temperature. The new mixed stream acts as the old stream 10, and thus there is no stream 44 and 45. The amount of extracted nitrogen 13 in the alternative process is equal to the sum of the amount of nitrogen stream 13 and 45 in the process shown in Figure 3. The reason why this alternative can be derived is that there is almost no difference in purity, pressure and temperature between the two nitrogen streams 10 and 43 as shown in Figure 3.

Another embodiment is shown in Figure 4. In this embodiment only a single distillation column is used. Once again, the input process air is not significantly compressed. Ambient air stream 1 is compressed to a pressure (for example, about 1.5 bar) that allows the air to flow into the distillation column 104 with reasonable pressure losses in a blower 100. Water, carbon dioxide and other impurities in the air stream 2 are removed in a purification unit 101. The purified air 3 is cooled to around 93 K in a multi-stream heat exchanger 102 to produce cooled air 4 and then further cooled to its dew point in another multi-stream heat exchanger 103. The resultant cooled air 5 is fed to a distillation column 104. The operating pressure at the top of column 104 is around 1.2 bar. The oxygen rich liquid 6 from the bottom of column 104 is vaporized in a reboiler 105a. A portion of the vaporized oxygen 7 is fed back to column 104, while another portion 8 is heated in heat exchanger 102 to around 283 K and hence forms the oxygen product stream 9. The purity of oxygen product 9 is around 95%. The nitrogen vapour 10 from the top of column 104 is heated to around 90.3 K in heat exchanger 103 to produce nitrogen stream 11 and then heated further to around 283 K in heat exchanger 102.

The resultant nitrogen stream 12 is split into three portions: about 50% is expelled from the apparatus as stream 13, the remaining part in stream 14 is further split with about 48% of the original volume directed as stream 20 for further compression and cooling, and the remainder, about 2% of the original volume forming stream 15.

The first part, expelled nitrogen 13, is vented after being used in the regeneration process in purification unit 101.

The second part, nitrogen stream 20, is compressed to about 4.9 bar in a multi-stage compressor 106 with water intercooling. The resultant compressed nitrogen 21 is cooled in a water cooler 107, and then cooled in heat exchanger 102 to its dew point. The cooled nitrogen 23 is condensed in a condenser 105b. The resultant nitrogen liquid 24 is subcooled to around 88 K or lower if a lower temperature cooling source is available in heat exchanger 103, and expanded to about 1.2 bar through a Joule-Thomson valve 115. The expanded nitrogen liquid 26 then is fed to column 104 as the reflux liquid for distillation column 104. Reboiler 105a and condenser 105b are heat linked to form a combined condenser/reboiler, as is commonly used in cryogenic air distillation cycles. The temperature difference of the linked

condenser/reboiler is around 1.2 K. The minimum approach temperature difference in heat exchangers 102 and 103 is also 1.2 K.

The third part, nitrogen stream 15, is compressed to 4.5 bar in a multi-stage compressor 108 with water intercooling. The resultant compressed nitrogen 16 is cooled in a water cooler 109, and then expanded in an expander 110. The expanded nitrogen 18 is heated to around 283 K in heat exchanger 102 and then vented 19.

There are some other alternatives which may be derived from the cycle described above:

1. The compressors 106 and 108 may be combined as one multi-stage compressor if the stream 15 is compressed to the same pressure as the stream 21.

2. The expansion cycle (streams 15, 16, 17 and 18; equipment 108, 109 and 110) may be not required if a smaller temperature difference is allowed in heat exchanger 102.

3. The amount of nitrogen in the expansion cycle (stream 15) is determined by the allowable temperature difference in heat exchanger 102. If a larger temperature difference is required, the splitting ratio of stream 15 can be increased (the range of the ratio is about 0~20%), and the splitting ratio of stream 13 can be reduced correspondingly. A compander may be used instead of the compressor 108 and expander 110.

4. A closed refrigeration cycle using nitrogen or other substances (methane, ammonia, and so on) as the medium may be applied instead of the expansion cycle.

5. The linked condenser/reboiler means that the reboiler and condenser are heat linked, in practice there are many different configurations which are commonly used in cryogenic air separation processes can be implemented. For example, the streams to be condensed can be directly condensed in the corresponding reboilers of the coupled condenser/reboilers.

6. The expansion cycle can be substituted by a following way: the air feed stream 3 is split into two portions: one portion has similar molar flow rate as stream 15, and this portion of air is used as the medium instead of nitrogen in the expansion cycle; another portion is cooled to the same temperature as stream 18 in heat exchanger 102; the two portions are combined and then cooled to the same temperature as stream 4 in heat exchanger 102; the combined stream substitutes stream 4 in the described process and the rest part is the same as the described process.

7. The expansion cycle can be modified as follows. After the water cooler 109 the nitrogen stream 17 is first cooled in heat exchanger 102 and then expanded in an expander before being heated by the heat exchanger 102. This is different to the Figure 4 arrangement where expansion in expander 110 occurs prior to heat exchange. In the modified cycle the cooled and expanded nitrogen stream is heated to around 283 K in heat exchanger 102 and then vented. The compression ratio for compressor 108 and the target temperature of stream

17 cooled in heat exchanger 102 are determined by the allowable temperature distribution in heat exchanger 102.

The principle of using distributed reboiling in the distillation column to reduce the irreversibilities can be applied in the process of Figure 4. Figure 5 shows a dual-reboiler cycle based on the process of Figure 4. The main difference between this cycle and the cycle shown in Figure 4 is the use of an additional reboiler 113a positioned in the distillation column 104 and the consequent division of the nitrogen stream from the distillation column 104 into a further part.

The nitrogen stream 20 is split into two portions. One part, stream 27 is about 67% of the volume of the stream 20 (the range can be 55~75 %) is subsequently treated in a similar manner to the stream 20 in Figure 4. Another part, stream 28 is about 33% of the volume of stream 20 (the corresponding range can be 25~45%) and this forms a further part of the original nitrogen stream 12. This further part, nitrogen stream 28, is compressed to about 3.1 bar in a multi-stage compressor 111 with water intercooling. The resultant compressed nitrogen 29 is cooled in a water cooler 112, and then cooled in heat exchanger 102 to its dew point. The cooled nitrogen 31 is then condensed in a condenser 113b. The nitrogen liquid 32 is subcooled to around 88 K or lower if a lower temperature cooling source is available in heat exchanger 103, and expanded to 1.2 bar 34 through a Joule-Thomson valve 114. The two nitrogen streams 26 and 34 are combined 35 and fed to column 104 as the reflux liquid for distillation.

In this arrangement, there are two reboilers 105a and 113a in column 104. The first reboiler 105a is placed at the bottom of column 104 as in the process of Figure 4. The second reboiler 113a is placed in the distillation column 104 one to five equilibrium stages below the feed stage of the air stream 5. The first reboiler 105a and first condenser 105b are heat linked as combined condenser/reboiler as in the Figure 3 process. The second reboiler 113a and second condenser 113b are heat linked in a similar way as reboiler 105a and condenser 105b. The temperature difference of the linked condenser/reboiler is around 1.2 K.

There are some other alternatives which may be derived from the cycle described above besides the alternatives mentioned for the cycle shown in Figure 4:

1. The compressors 106 and 111 may be combined as one multi-stage compressor. A portion of nitrogen can be extracted from an intermediate stage of the new compressor, and this stream behaves like stream 29; another portion of nitrogen is extracted from the outlet stage of the new compressor, and this stream behaves like stream 21.

2. The use of an intermediate reboiler 113a means that column 104 can be divided into two columns by the reboiler.

A key idea of the above two cycles is not to compress oxygen in the air feed as generally done in Linde's double-column distillation system. This provides a consequent reduction in the mass flow through compressors and thus a reduction in power consumption.

An alternative way to achieve a reduction in power consumption is to not significantly compress all the air feed to a pressure that is obviously above ambient pressure. This also provides a consequent reduction in the mass flow through compressors, and a process of this type can still take advantage of the realisation that 'excess' nitrogen is present by ensuring that, following on from the non-compression of incoming nitrogen in the input process air, nitrogen produced by the process is rejected without expansion or compression. An embodiment of such an alternative cycle is shown in Figure 6.

In this cycle, the ambient air stream 1 is compressed to a pressure (for example, about 1.5 bar) that allows for air flow into the first distillation column 104 with reasonable pressure losses in a blower 100. Water, carbon dioxide and other impurities in the air stream 2 are removed in a purification unit 101. In contrast to the processes of Figures 4 and 5, some of the incoming air 3 is subject to compression.

Thus, the purified air 3 is split into two portions. A first part of the incoming air 224 is directed toward the distillation column 104 without compression, and this part forms about 25% (up to 35%) of the total incoming air volume. The remainder of the incoming air, in stream 204, is hence about 75% (the range can be 65 to 100%) of the volume. The major portion in stream 204 is compressed to about 5.3 bar in a multi-stage compressor 302 with water intercooling. The resultant compressed air 205 is cooled in a water cooler 303. The cooled air stream 206 is then split into two portions to form second and third parts of the original incoming process air. The second part, in stream 207 forms about 98% (the range can be 85 to 100%) of the volume of stream 204. The third part, in stream 226 forms about 2% (the corresponding range can be 0 to 15%) of that volume. When the mass flow in stream 226 is increased, the mass flow in stream 224 is reduced correspondingly, so that the air feed 229 to the first distillation column 104 is around 25 % (up to 35%) of the mass of the air feed 1.

The first part of the incoming air in stream 224 is cooled down to its dew point in a multi-stream heat exchanger 102. This forms cooled air 225, which is joined with air from the third part 226 as explained below to form feed air for the first distillation column 104.

The second part of the incoming air in stream 207 is cooled to its dew point in the multi-stream heat exchanger 102 and fed to a higher pressure second distillation column 305 at the bottom stage. The operating pressure of the top stage of the second distillation column 305 is around 4.75 bar. Crude liquid oxygen 209 is extracted from the bottom of the second distillation column 305. The oxygen purity in stream 209 is around 38 mole%. The crude oxygen stream 209 is subcooled to around 92.5 K or lower if a lower temperature cooling source is available in a multi-stream heat exchanger 103 and then expanded to about 1.3 bar

in a Joule-Thomson valve 307. The resultant liquid stream 211 is fed to the lower pressure first distillation column 104. The operating pressure of the top stage of column 104 is about 1.2 bar. The nitrogen vapour 212 from the top of the second column 305 is condensed in a condenser 105b and split into two portions. A first portion 213 forms about 55% of the total volume and returns back to column 305 as reflux. A second portion 214 is the remainder (about 45%) and this is subcooled in the heat exchanger 103, then expanded to about 1.2 bar in a Joule-Thomson valve 310 before being fed to the first distillation column 104 as the reflux.

The third part of the incoming air, air stream 226, is expanded to around 1.25 bar in an expander 311 and then cooled down to its dew point 228 in the heat exchanger 102. The resultant cooled air stream 228 then joins with stream 225 as noted above. The combined cooled air stream 229 is fed to column 104 at one to five equilibrium stages below the feed stage of stream 211. By expansion of the third part of the incoming air 226, the necessary refrigeration energy of heat exchanger 102 can be satisfied. If the pinch point needs to be adjusted, a new compressor can be installed along the path 226. One alternative way for the expansion of the third part of the incoming air is that the third part is split from the feed air prior to the compression and cooling, i.e. stream 204 is split into two portions, being a first portion 226 and a second portion as new stream 204. The new stream 204 behaves the same as the old stream 204 in Figure 6 but without the splitting after compression and cooling. The new stream 226 behaves the same as the old stream 226 in Figure 6 after it is compressed and cooled. A compander may be used instead of the new installed compressor along the path 226 and expander 311.

The nitrogen vapour 10 from the top of column 104 is heated in heat exchanger 103 to provide the necessary refrigeration energy for cooling the incoming nitrogen reflux stream and crude oxygen stream and then heated further to about 283 K in heat exchanger 102, thereby cooling the incoming air streams. The resultant nitrogen 13 at about ambient temperature and pressure is vented after being used in the regeneration process in purification unit 101. The purity of this nitrogen 13 is around 99%. The oxygen liquid 6 from the bottom of column 104 is vaporized in a reboiler 105a. A portion of the vaporized oxygen 7 is fed back to column 104, while another portion 8 is heated in heat exchanger 102 to around 283 K to form the output purified oxygen stream 9. The purity of oxygen product 9 is around 95%.

Figure 7 is another modification to the embodiment of Figure 4 using dual reboilers. The same reference numbers are used and where the system is similar the description is not repeated. In modified cycle of Figure 7, a first reboiler 105a may receive the oxygen stream 6 from the distillation column 104 as discussed for the process shown in Figure 4. The modified cycle differs from that of Figure 4 in that a second reboiler 713a is placed part way up the distillation column 104, preferably below the feed stage, for example one to ten equilibrium stages below the feed stage.

The second reboiler 713a is a part of a combined condenser/reboiler 713a, 713b that is used to condense a compressed part of the nitrogen stream. The part of the nitrogen stream that is condensed in the second condenser/reboiler 713a, 713b is extracted part way up the distillation column, preferably above the feed stage, for example one to twenty equilibrium stages above the feed stage. The extracted nitrogen (stream 710, nitrogen mole fraction is around 89%), flowing via streams 712 and 720 is heated to substantially ambient temperature against the feed streams to the distillation column 104 in heat exchangers 102 and 103. Stream 720 is then compressed to around 2.8 bar in the compressor 706 to produce compressed stream 721, which is cooled by cooler 707 producing stream 722. After the compression and cooling the extracted nitrogen 722 is further cooled by heat exchange with the output oxygen and nitrogen product streams from the distillation column in heat exchanger 102. The further cooled nitrogen 723 is then condensed in the second condenser/reboiler that includes the condenser 713b. After the condenser 713b the condensed extracted nitrogen 724 is cooled by heat exchange with the nitrogen product streams from the distillation column in heat exchanger 103 and the resultant nitrogen stream 725 is expanded through a Joule-Thomson valve 715 before being returned back to the distillation column 104. The extracted nitrogen is returned part way up the distillation column 104, preferably above the feed stage, and more preferably above the stage where it is extracted, for example zero to five equilibrium stages above the extracted stage.

Compared to the process shown in Figure 4, the advantage of this cycle is that volume flow through the compressor 106 has been reduced by around 30% (the range can be around 10-60%). Compared to the process shown in Figure 5, the volume flow through compressor 106 is approximately the same, and the volume flow through compressor 111 in the Figure 5 system and 706 in the Figure 7 system is also approximately the same. However, the pressure ratio for compressor 706 is lower than for compressor 111. Thus power can be saved.

Figure 8 shows a three-reboiler cycle based on the process of Figure 5. The same reference numbers are used and where the system is similar the description is not repeated. A third reboiler 613a is positioned in the distillation column 104 and consequently the nitrogen stream from the distillation column 104 is divided into a further part. Thus, in the Figure 8 embodiment the nitrogen stream 20 is split into three portions instead of two portions as in Figure 5. One part, stream 27 is about 61% of the volume of the stream 20 (the range can be 55~75 %) and this is subsequently treated in a similar manner to the stream 27 in Figure 5. Another part, stream 28 is about 21% of the volume of the stream 20 (the range can be 12~45 %) this is subsequently treated in a similar manner to the stream 28 in Figure 5. The third part, stream 628 is about 18% of the volume of stream 20 (the corresponding range can be 12~45%) and this forms a further part of the original nitrogen stream 12. This further part,

nitrogen stream 628, is compressed to about 2.7 bar in a multi-stage compressor 611 with water intercooling. The resultant compressed nitrogen 629 is cooled in a water cooler 612, and then cooled in heat exchanger 102 to its dew point. The cooled nitrogen 631 is then condensed in a condenser 613b, which is a part of a dual reboiler/condenser 613a, 613b. The nitrogen liquid 632 is subcooled to around 88 K, or lower if a lower temperature cooling source is available in heat exchanger 103, and the resultant nitrogen stream 633 is then expanded to 1.2 bar through a Joule-Thomson valve 614. This produces nitrogen stream 634, which is combined with the other two streams 26, 34 to form combined stream 35, which is fed to column 104 as the reflux liquid for distillation as in Figure 5.

In this arrangement, there are three reboilers 105a, 113a and 613a in column 104. The first reboiler 105a is placed at the bottom of column 104 as in the process of Figure 5. The second reboiler 113a is placed in the distillation column 104 one to five equilibrium stages below the third reboiler 613a. The third reboiler 613a is placed in the distillation column 104 one to five equilibrium stages below the feed stage of the air stream 5. The first reboiler 105a and first condenser 105b are heat linked as combined condenser/reboiler as in the Figure 5 process. The second reboiler 113a and second condenser 113b are heat linked in a similar way as reboiler 105a and condenser 105b. The third reboiler 613a and third condenser 613b are also heat linked in a similar way as reboiler 105a and condenser 105b. The temperature difference of the linked condenser/reboiler is around 1.2K.

Figures 9 to 12 show additional some refinements and alternatives. The cycle of Figure 9 is derived from the cycle of Figure 7, described above, and similar parts are not described in any great detail. The cycle of Figure 9 differs from that of Figure 7 in that the stream 710 extracted part way up the column 104 is omitted and stream 720 is instead obtained by splitting the incoming air stream 3 after filtering and purification. Thus, a portion of the incoming air is split from the purified air (stream 3) to form stream 720. The flow ratio between stream 720 and stream 3 is 46% in an example embodiment and the possible range is 30~70%. This portion of air is compressed to 310 kPa (possible range: 250-450 kPa) in the compressor 706; the compressed air stream 721 is cooled in a cooler 707 and the cooled air stream 722 is split into two portions. One portion, stream 740, is around 57% of stream 722 (the possible range is 30~99%) and this behaves the same as stream 722 in the process in Figure 7. Another portion, stream 741, is around 43% of stream 722 (the possible range is 1-70%) and this portion 741 is cooled to sub-ambient temperature in the multi-stream heat exchanger 102 (the temperature is dependent on the distribution of temperature differences in the heat exchanger), expanded to the same pressure as stream 731 in the expander 110, and then combined with the cooled air stream 731 to form a mixed air stream 4. This mixed air stream 4 behaves the same as the stream 4 in the process of Figure 7. Stream 741 may be further compressed in a compressor (not shown in Figure 9) prior to being cooled in the heat

exchanger 102. The outlet pressure of the compressor is dependent on the distribution of temperature differences in the heat exchanger 102. The compressor and the expander 110 may be combined as a compander.

This modification of Figure 9 can provide two main improvements compared to the cycle of Figure 7:

(1) if the impure air stream 710 in Figure 7 is extracted at the same stage as the air stream 5 is fed, stream 710 and stream 5 will have the same composition, thus a portion of the air feed can be used as the working fluid to be condensed in the condenser 713b. The advantage is that the pressure losses along the flow path of the working fluid can be reduced. This is implemented by the stream 740 in Figure 9.

(2) the refrigeration cycle is generated in the following way: a portion of the compressed and cooled air (stream 741) is cooled to subambient temperature in heat exchanger 102 and then expanded, and then mixed with the air stream.

In all the cycles discussed above impurities (H_2O, CO_2 and others) are removed in purification unit 101. This purification is commonly done by molecular sieve adsorption in industry today. Since the incoming air is at a much lower operating pressure than in conventional air separation processes (around 160 kPa compared to perhaps 400-600 kPa) then a molecular sieve device may not work so effectively and the lower operating pressure will increase the size of the purification unit and thus the investment cost. Hence, further advantages may be obtained by the use of purification technologies utilising a reversing heat exchanger as shown in Figure 10 instead of the molecular sieve adsorption. With a reversing heat exchanger the impurities in the air freeze out in the heat exchanger and are later removed by the regeneration gas (N_2 and/or O_2). Such scheme is illustrated in Figure 10. When air flows through the path A, the air is cooled to sub-ambient temperature, impurities are removed by freezing, and the regeneration gas flows through the path B to clean the impurities; later the flow paths of the air and the regeneration gas switch; and then later the flow paths switch back. The heat exchanger 102 can be utilised as the reversing heat exchanger.

When the reversing heat exchanger is applied to the process shown in Figure 9, the cycle is modified as shown in Figure 11. The purification unit 101 is removed. The air streams 730, 740 and 741 are purified as shown in Figure 10 by means of the heat exchanger 102. The nitrogen used for reflux (stream 750) is split from the nitrogen product prior to being heated in the heat exchanger 102. The split nitrogen stream has the same flow of stream 20 in Figure 9 and of stream 20 in Figure 7. The remaining nitrogen stream (stream 12) is heated to ambient temperature (stream 13). A portion or all of the nitrogen stream 12 is used as the regeneration gas as shown in Figure 10. In addition, the oxygen (stream 8) may also

be used as the regeneration gas as shown in Figure 10 if the impurity levels in the final oxygen product (stream 9) are acceptable for industrial application.

In the event that there are multiple air streams to be purified (e.g. three air streams 730, 740 and 741 in Figure 11) then the regeneration gas may be split into several streams based on the requirement of the removal of impurities by the regeneration gas.

Figure 12 shows a further alternative in which both a reversing heat exchanger system and a purification unit such as a molecular sieve adsorption unit are used. When a portion of the air feed is obviously compressed, this portion can be purified in a purification unit as normally done by molecular sieve adsorption, while the other portion that has not been obviously compressed can be purified by using the reversing heat exchanger. The advantage is that more gas can be used for the regeneration since less air is to be purified in the reversing heat exchanger. As shown in the example of Figure 12, the air feed is split into two portions after dust removal in a filter. One portion (stream 760) has the same flow of stream 730 in Figure 11. This portion is treated in the same way as the air stream 1 in Figure 11 and the resulting compressed air stream 730 then behaves like stream 730 in Figure 11. Another portion (stream 720) has the same flow and behaves the same as stream 720 in Figure 9. The resulting compressed and cooled air stream 761 is then purified in a molecular sieve adsorption unit 101. The resulting purified air stream 722 then behaves the same as stream 722 in Figure 9. The amount of the gas to be used for regeneration is distributed based on the requirement for the removal of impurities.

A comparison of the plant performance for the cycles described above in relation to Figures 4, 5, 6, 7 and 8 is shown in Table 1. A conventional Linde's double-column cycle is studied as the base cycle. The cycle developed by Manson Benedict and disclosed in US 2627731 is also included. As can be seen, the performance of the processes discussed in relation to Figures 4, 5, 6, 7 and 8 is obviously much improved in power consumption compared to the prior art processes. Notice that the specific power consumption is based on the results from computer simulation by the authors. The value reported by Benedict is larger than 0.263 kWh/kg oxygen. Compared to the base Linde cycle, the specific power consumption has been reduced by 13.1%, 19.7%, 17.0%, 24.0% and 23.1% respectively in the three processes discussed above in relation to Figures 4, 5, 6, 7 and 8.

Table 1: Comparison of the plant performance

	Oxygen purity (%)	Oxygen recovery rate (%)	Specific power consumption, (kWh/kg oxygen)
Linde's double-column cycle	95	99.3	0.229
The process of US 2627731	90	96	0.263
The process shown in Figure 4	95.5	98.3	0.199
The process shown in Figure 5	95.6	98.4	0.184

The process shown in Figure 6	95.1	98.5	0.190
The process shown in Figure 7	95.1	97.9	0.174
The process shown in Figure 8	95.5	98.5	0.176

Figure 13 illustrates the mass balance in the proposed vapour compression process as shown in Figure 4. As can be seen, for 1000 mol air feed, approximately 580 mol nitrogen needs to be compressed to provide the necessary reflux in this case. This is to be compared with Linde's double-column cycle, all the air feed is compressed, which means that 1000 mol air has to be compressed. Similarly, in the proposed vapour compression process with dual-reboiler as shown in Figure 5, approximately 580 mol nitrogen needs to be compressed. However, around 33% is compressed to a lower pressure of about 3.1 bar, which gives rise to further efficiency gains.

Figure 14 illustrates the mass balance in the proposed 'air bypass' process as shown in Figure 6. As can be seen, 1000 mol air feed has been compressed and fed to the higher pressure column, while 340 mol air has been fed to the lower pressure column directly without compression. As a result, around 1000/(1000+340) = 75% of the total air feed is compressed. Compared to Linde's double-column cycle, the mass flow through compressors per unit air feed in the proposed cycles in this invention has been reduced significantly.

Notice that Figure 13 and Figure 14 are used for the purpose of approximate schematic illustration. In practice the amount of nitrogen needs to be compressed in Figure 13 is larger than 580 mol, since some vapour forms when the liquid nitrogen is expanded through a Joule-Thomson valve. Moreover, the power consumed in the blowers should be included when comparing the plant performance for the entire cycles.

The processes described herein focus on ways to reduce the mass flow through compressors in air separation processes. The basic point is the fact that the required amount of nitrogen reflux liquid for distillation is smaller than the amount of nitrogen in the air feed. New air separation processes are proposed in which only the nitrogen or only a portion of the air feed is compressed.

In summary, the following proposals and advantages are described herein:

(1) An air separation process by cryogenic distillation in a single column is proposed to separate air into its main components, in which the air feed is compressed only to a low pressure close to ambient pressure (to give allowable pressure losses in the entire system); a portion of the nitrogen product (around 90% of the nitrogen flow in the air feed) is compressed to a pressure (the pressure level is around 4~5.5 bar; the key point is that the nitrogen can be condensed by the oxygen liquid at the bottom of the distillation column) at around ambient pressure and temperature, cooled to its dew point, condensed by the boiling

oxygen at the bottom of the distillation column, subcooled in a heat exchanger, expanded to the operating pressure of the distillation column, and fed to the distillation column as reflux.

(2) For the process described in (1), the necessary refrigeration energy is produced in such a way that a portion of the nitrogen product (0~20% of the nitrogen flow in the air feed) is compressed at around ambient pressure and temperature, expanded at ambient temperature or subambient temperature after being cooled by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation, and then heated to ambient temperature.

(3) Possible advantageous alternatives and adaptations to this process are described above.

(4) An air separation process by cryogenic distillation is proposed to separate air into its main components, in which the air feed is compressed only to a low pressure which may be a pressure close to ambient pressure (to give allowable pressure losses in the entire system); a portion of the nitrogen product (around 50% of the nitrogen flow in the air feed) is compressed to a pressure (the pressure level is around 4~5.5 bar; the key point is that the nitrogen can be condensed by oxygen liquid at the bottom of the distillation column) at around ambient conditions, cooled to its dew point, condensed by the boiling oxygen at the bottom of a distillation column, subcooled in a heat exchanger, expanded to the operating pressure of the distillation column, and fed to the distillation column as reflux; an intermediate reboiler is placed 1~5 equilibrium stages below the feed stage of air stream in the distillation column; a portion of the nitrogen product (around 25% of the nitrogen flow in the air feed) is compressed to a pressure (the pressure level is around 2.5~3.5 bar; the key point is that the nitrogen can be condensed by boiling liquid in the intermediate reboiler) at around ambient conditions, cooled to its dew point, condensed by the boiling liquid in the intermediate reboiler, subcooled in a heat exchanger, expanded to the operating pressure of the distillation column, and fed to the distillation column as reflux.

(5) For the process described in (4), the necessary refrigeration energy is produced in such a way that a portion of the nitrogen product (0~20% of the nitrogen flow in the air feed) is compressed at around ambient pressure and temperature, expanded at ambient temperature or subambient temperature after being cooled by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation, and then heated to ambient temperature.

(6) Possible advantageous alternatives and adaptations to the process of (4) and (5) are described above.

(7) An air separation process by cryogenic distillation in double columns is proposed to separate air into its main components; the operating pressure of one column (named as higher pressure column) is around 5 bar (the range can be 4.5~5.5 bar), and the

operating pressure of another column (named as lower pressure column) is around 1.3 bar (the range can be 1.1~2 bar); the air feed is compressed only to a low pressure close to ambient pressure (to give allowable pressure losses in the entire system); the air feed is split into two portions; one portion (around 75%, the range can be 65~100%) is further compressed to a higher pressure (the pressure level is around 4~6 bar; the key point is that the nitrogen vapour from the higher pressure column can be condensed by the oxygen liquid at the bottom of the lower pressure column), and split into two portions: a small portion (around 2%, the range can be 0~20%) is expanded in an expander to produce the necessary refrigeration energy, while another portion is separated in the double columns in a way similar to Linde's double distillation column; the other portion of the air feed (around 25%) is cooled to its dew point in a heat exchanger and fed to the lower pressure column for separation; the portion of air feed expanded in the expander is cooled to its dew point in a heat exchanger and fed to the lower pressure column for separation.

(8) Although an oxygen purity of 95% is used in the processes described in the main text, all of these processes can easily be further developed to separate air into its products with higher purities (for example, oxygen-99.5%, argon-91% and nitrogen-99.1%) by using an argon separation column of the type commonly used in cryogenic air separation processes.

(9) Although the pressure of the products of the air separation processes described in the main text is around ambient pressure, the processes can easily be further developed to produce products at higher pressure by compressing the products directly using compressors or pumping the liquid products.

The new processes may usefully be utilised in gas separation for oxy-combustion processes related to carbon dioxide capture. However, the application of the new process is not limited to this area. Instead, the new air separation process can be used in any process where cryogenic air separation is required. Examples are industrial plants such as ammonia plants, steel plants, gasification plants, coal power plants and any application where oxygen is needed.

CLAIMS:

1. An air separation process for the production of purified oxygen from air, the process comprising:

using a distillation column to separate an incoming process stream into a nitrogen stream and an oxygen rich stream, the distillation column being at low pressure or at substantially ambient pressure;

wherein only a part of or none of the input process air is compressed before distillation, with the remainder of the input process air being supplied to the distillation column at low pressure or substantially ambient pressure; and

wherein at least some of a nitrogen stream produced by the distillation column is rejected at substantially ambient pressure and temperature after heat exchange and without significant expansion or compression;

such that during the air separation process a portion of the nitrogen in the incoming process air that is not necessary for the production of oxygen of the desired purity does not undergo any significant compression.

2. A process as claimed in claim 1, wherein the pressure of the distillation column is below 2 bar.

3. A process as claimed in claim 1 or 2, wherein the process includes compression and cooling of a portion of the nitrogen stream produced by the distillation column.

4. A process as claimed in claim 3, wherein the compression and cooling is followed by expansion at ambient temperature or subambient temperature after being cooled by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation to enable further heat exchange to cool incoming process air.

5. A process as claimed in claim 3 or 4, wherein the cold nitrogen stream formed by the compression and cooling is used as reflux in the distillation column.

6. *A process as claimed in claim 5, wherein the nitrogen stream from the* distillation column is used for heat exchange to cool incoming process air prior to the compression and cooling.

7. A process as claimed in any preceding claim, wherein none of the input process air is significantly compressed and the required cooling for distillation is achieved by compression and cooling of a part of one or more nitrogen streams obtained after separation by distillation.

8. A process as claimed in claim 5, 6 or 7, wherein the nitrogen stream produced by the distillation column is split into at least two parts, with a first part being expelled to atmosphere at substantially ambient temperature and pressure after heat exchange with incoming process air, and a second part being compressed and cooled before heat exchange with other process streams and then subsequently expanded and used as the reflux for the distillation column.

9. A process as claimed in claim 8, wherein after the compression and cooling the second part of the nitrogen stream is cooled in heat exchange with at least a part of a nitrogen stream from the distillation column and/or at least a part of an oxygen stream from the distillation column, and is condensed in a condenser/reboiler that includes a reboiler of the distillation column before being expanded and used as reflux in the distillation column.

10. A process as claimed in claim 8 or 9, wherein the nitrogen stream produced by the distillation column is split into at least three parts, with a third part being used in a compression, cooling and expansion cycle to produce further cold for heat exchange with the incoming process air before being expelled to atmosphere at substantially ambient temperature and pressure.

11. A process as claimed in claim 10, wherein the first part is between 30% and 60% of the total volume, the second part is between 60% and 30% of the total volume and the third part is between 1% and 20% of the total volume.

12. A process as claimed in any of claims 8 to 11, wherein the distillation column is equipped with two reboilers comprising a first reboiler that receives the oxygen stream from the distillation column and is used to produce the output purified oxygen stream; and a second reboiler that is placed part way up the distillation column.

13. A process as claimed in claim 12, wherein the first reboiler is part of a combined condenser/reboiler that is used to condense the second part of the nitrogen stream, and the second reboiler is a part of a combined condenser/reboiler that is used to condense a further compressed part of the nitrogen stream, the further compressed part of the nitrogen

stream being a further or fourth part of the nitrogen stream that is split from the nitrogen stream produced by the distillation column and processed in a similar manner to the second part thereof.

14. A process as claimed in claim 13, wherein the further or fourth part is obtained by taking a portion of second part at a ratio of reduced second part : fourth part of between 55% : 45% and 75% : 25%.

15. A process as claimed in claim 13 or 14, wherein the liquefied nitrogen streams from each of the two condensers is expanded and combined before being used as reflux for the distillation column.

16. A process as claimed in any preceding claim and utilising multiple distillation columns.

17. A process as claimed in any of claims 1 to 7, wherein the process utilises multiple distillation columns including first and second distillation columns, one or both of which are operated at low pressure or at substantially ambient pressure; and the process comprises providing input process air to the first distillation column in which the air is separated into a nitrogen stream and an oxygen rich stream; sending the oxygen rich stream to the second distillation column; compressing and cooling at least a part of the nitrogen stream from the first distillation column and/or a part of the nitrogen stream from the second distillation column; using the compressed and cooled nitrogen as reflux for at least one of the first distillation column and the second distillation column; and further separating the oxygen rich stream in the second distillation column.

18. A process as claimed in claim 17 wherein the input process air does not undergo significant compression and wherein both of the distillation columns are operated at similar low pressure to the pressure of the input process air.

19. A process as claimed in claim 17 or 18, comprising rejecting at least some of the nitrogen stream from the second distillation column at ambient temperature after heat exchange and without expansion or compression.

20. A process as claimed in claim 17, 18 or 19, wherein the input process air is cooled to distillation temperature by heat exchange with at least a part of a nitrogen stream

from the second distillation column and/or at least a part of an oxygen stream from the second distillation column and/or at least a part of the nitrogen stream from the first distillation column.

21. A process as claimed in any of claims 17 to 20, wherein only a part of the nitrogen stream from the first distillation column and/or from the second distillation column is compressed and cooled.

22. A process as claimed in claim 21, wherein the part of the nitrogen stream that is compressed and cooled is condensed and supplied to one or both distillation columns as *liquid nitrogen for reflux*.

23. A process as claimed in claim 1, 2 or 3, wherein a cold process stream formed by compression and cooling is used as feed gas for a further distillation column, with a nitrogen product of this further distillation column being used as reflux for the low pressure distillation column.

24. A process as claimed in claim 1, 2, 3, or 23, wherein a part of the incoming process air is compressed and cooled and used to produce reflux for distillation and separation of air and another part of the incoming process air is conveyed to the distillation column at low pressure or substantially ambient pressure.

25. A process as claimed in claim 24, wherein the nitrogen stream produced by the distillation column at low pressure or substantially ambient pressure is expelled to atmosphere at ambient pressure and temperature after heat exchange with other process streams.

26. A process as claimed in claim 24 or 25 using multiple distillation columns, wherein the distillation column at low pressure or substantially ambient pressure is a first distillation column and receives the part of the incoming process air that is not significantly compressed, the process further comprising using a second distillation column that receives the compressed and cooled input process air as a feed gas.

27. A process as claimed in claim 26, wherein the oxygen rich stream from the *second distillation column is used, after expansion, as a further feed for the first distillation* column.

28. A process as claimed in claim 26 or 27, wherein nitrogen produced by the second distillation column is used as reflux for the first distillation column and/or as reflux for the second distillation column.

29. A process as claimed in claim 26, 27 or 28, wherein the oxygen rich output stream of the first distillation column is reboiled by a reboiler that is a combined condenser/reboiler also used for condensing the nitrogen output from the second distillation column.

30. A process as claimed in any of claims 26 to 29, comprising splitting the input process air into parts, of which a first part is passed to the first distillation column without significant compression and another part is compressed and cooled, wherein the another part is further split into parts, being a second part that is used as the feed gas for the second distillation column and a third part that is expanded and cooled before being recombined with the first part and used as feed gas for the first distillation column.

31. An air separation apparatus for the production of purified oxygen from air, the apparatus comprising:

a distillation column arranged to separate an incoming process stream into a nitrogen stream and an oxygen rich stream, the distillation column being at low pressure or at substantially ambient pressure;

wherein only a part of or none of the input process air is compressed before distillation, with the remainder of the input process air being supplied to the distillation column at low pressure or substantially ambient pressure; and

wherein at least some of a nitrogen stream produced by the distillation column is rejected at substantially ambient pressure and temperature after heat exchange and without significant expansion or compression;

such that during the air separation process a portion of the nitrogen in the incoming process air that is not necessary for the production of oxygen of the desired purity does not undergo any significant compression.

32. An apparatus as claimed in claim 31, wherein the pressure of the distillation column is below 2 bar.

33. An apparatus as claimed in claim 31 or 32, wherein the apparatus includes a compression and cooling cycle for compression and cooling of a portion of the nitrogen stream produced by the distillation column

34. An apparatus as claimed in claim 33 wherein the compression and cooling cycle is followed by an expander for expansion of this portion of the nitrogen stream at ambient temperature or subambient temperature after being cooled by heat exchange with one or more of the nitrogen and oxygen product streams produced by distillation to enable further heat exchange to cool incoming process air.

35. An apparatus as claimed in claim 33 or 34, wherein the cold nitrogen stream formed by the compression and cooling is used as reflux in the distillation column.

36. An apparatus as claimed in claim 35, wherein the nitrogen stream from the distillation column is passed through a heat exchanger in order to cool incoming process air prior to the compression and cooling.

37. An apparatus as claimed in any preceding claim, wherein none of the input process air is significantly compressed and the required cooling is achieved by compression and cooling of a part of one or more nitrogen streams or nitrogen rich streams obtain after separation by distillation.

38. An apparatus as claimed in claim 35, 36 or 37, wherein the nitrogen stream produced by the distillation column is split into at least two parts, with a first part being expelled to atmosphere at substantially ambient temperature and pressure after passing through a heat exchanger for heat exchange with incoming process air, and a second part being passed to a compression and cooling cycle before heat exchange in a heat exchanger with other process streams and then subsequently expanded in an expansion valve and used as the reflux for the distillation column.

39. An apparatus as claimed in claim 38 wherein after the compression and cooling cycle the second part is cooled in a heat exchanger for heat exchange with at least a part of a nitrogen stream from the distillation column and/or at least a part of an oxygen stream from the distillation column and is condensed in a condenser/reboiler that includes a reboiler of the distillation column before being expanded and used as reflux in the distillation column.

40. An apparatus as claimed in claim 38 or 39 wherein the nitrogen stream produced by the distillation column is split into at least three parts, with a third part being used in a compression, cooling and expansion cycle to produce further cold for heat exchange in a

heat exchanger with the incoming process air before being expelled to atmosphere at substantially ambient temperature and pressure.

41. An apparatus as claimed in claim 40, the apparatus being arranged to split the nitrogen stream produced by the distillation column into three parts, the first part being between 30% and 60% of the total volume, the second part being between 60% and 30% of the total volume and the third part being between 1% and 20% of the total volume.

42. An apparatus as claimed in any of claims 38 to 41, wherein the distillation column is equipped with two reboilers comprising a first reboiler that receives the oxygen stream from the distillation column and is used to produce the output purified oxygen stream; and a second reboiler that is placed part way up the distillation column.

43. An apparatus as claimed in claim 42, wherein the first reboiler is part of a combined condenser/reboiler that is used to condense the second part of the nitrogen stream, and the second reboiler is a part of a combined condenser/reboiler that is used to condense a further compressed part of the nitrogen stream, the further compressed part of the nitrogen stream being a further or fourth part of the nitrogen stream that is split from the nitrogen stream produced by the distillation column and processed in a similar manner to the second part thereof.

44. An apparatus as claimed in claim 43 arranged to create the further or fourth part by splitting off a portion of second part at a ratio of reduced second part : fourth part of between 55% : 45% and 75% : 25%.

45. An apparatus as claimed in claim 43 or 44, wherein the liquid nitrogen streams from each of the two condensers are each expanded in an expansion valve and then are combined before being used as reflux for the distillation column.

46. An apparatus as claimed in any of claims 31 to 45 comprising multiple distillation columns.

47. An apparatus as claimed in any of claims 31 to 37 comprising multiple distillation columns including first and second distillation columns, one or both of which are operated at low pressure or at substantially ambient pressure and wherein the first distillation column is for separating input process air into a nitrogen stream and an oxygen rich stream; the second distillation column is for receiving the oxygen rich stream and further separating it;

and the apparatus comprises a compressor and a cooler for compressing and cooling at least a part of the nitrogen stream from the first distillation column and/or a part of the nitrogen stream from the second distillation column; wherein the apparatus is arranged such that the compressed and cooled nitrogen is supplied as reflux for at least one of the first distillation column and the second distillation column.

48. An apparatus as claimed in claim 47, including an input air path for supplying process air from the atmosphere wherein there is no compressor in the input air path such that the air is supplied to the distillation column without significant compression and wherein both of the distillation columns are operated at similar pressure to the pressure of the input process air.

49. An apparatus as claimed in claim 47 or 48 wherein the apparatus is arranged to reject at least some of the nitrogen stream from the second distillation column at ambient temperature after heat exchange and without expansion or compression.

50. An apparatus as claimed in claim 47, 48 or 49, comprising one or more heat exchanger(s) for cooling of the input process air to distillation temperature, wherein the heat exchanger(s) are fluidly connected within the apparatus for heat exchange between the input process air and at least a part of a nitrogen stream from the second distillation column and/or heat exchange between the input process air and at least a part of an oxygen stream from the second distillation column and/or heat exchange between the input process air and some or all of the nitrogen stream from the first distillation column.

51. An apparatus as claimed in any of claims 47 to 50 wherein the apparatus is arranged to divide the nitrogen stream from the first distillation column and/or the nitrogen stream from the second distillation column such that only a part of this nitrogen stream is compressed and cooled for use as reflux.

52. An apparatus as claimed in claim 51, comprising a condenser for condensing the part of the nitrogen stream after it is compressed and cooled, wherein the liquid nitrogen is supplied to one or both of the distillation columns as reflux.

53. An apparatus as claimed in claim 31, 32 or 33, comprising a further distillation column, wherein a cold process stream formed by compression and cooling is used as feed gas for this further distillation column with a nitrogen product of this further distillation column being used as reflux for the low pressure distillation column.

54. An apparatus as claimed in claim 31, 32, 33 or 53 comprising a compression and cooling cycle for compressing and cooling a part of the incoming process air to enable it to be used to generate reflux for distillation and separation of air, wherein another part of the incoming process air is conveyed to the low pressure distillation column at low pressure or substantially ambient pressure.

55. An apparatus as claimed in claim 54, wherein the nitrogen stream produced by the distillation column at low pressure or substantially ambient pressure is expelled to atmosphere at ambient pressure and temperature after heat exchange with other process streams.

56. An apparatus as claimed in claim 54 or 55 comprising multiple distillation columns, wherein the distillation column at low pressure or substantially ambient pressure is a first distillation column and is arranged to receive the part of the incoming process air that is not significantly compressed along with reflux generated from the incoming process air that is subject to compression and cooling, and wherein a second distillation column is arranged to receive compressed and cooled input process air as a feed gas.

57. An apparatus as claimed in claim 56 wherein the oxygen rich stream from the second distillation column is conveyed to the first distillation column, after expansion, as a further feed for the first distillation column.

58. An apparatus as claimed in claim 56 or 57, wherein nitrogen produced by the second distillation column is used as reflux for the first distillation column and/or as reflux for the second distillation column.

59. An apparatus as claimed in claim 56, 57 or 58, wherein the apparatus includes a reboiler for reboiling the oxygen rich output stream of the first distillation column, the reboiler being in a combined condenser/reboiler that is also used for condensing the nitrogen output from the second distillation column.

60. An apparatus as claimed in any of claims 56 to 59, wherein the input process air is split into parts, of which a first part is passed to the first distillation column without significant compression and another part is compressed and cooled, wherein the another part is further split into parts, being a second part that is used as the feed gas for the second

distillation column and a third part that is expanded and cooled before being recombined with the first part and used as feed gas for the first distillation column.

61. An apparatus as claimed in any of claims 31 to 60, comprising an outlet for withdrawing the purified oxygen, and/or a storage tank for storing the purified oxygen for future withdrawal and use by a consumer.

62. An air separation process for producing purified oxygen substantially as hereinbefore described with reference to Figure 3, Figures 4 and 7, Figures 5 and 7 or Figures *6 and 8*.

63. An air separation apparatus for producing purified oxygen substantially as hereinbefore described with reference to Figure 3, Figures 4 and 7, Figures 5 and 7 or Figures *6 and 8*.

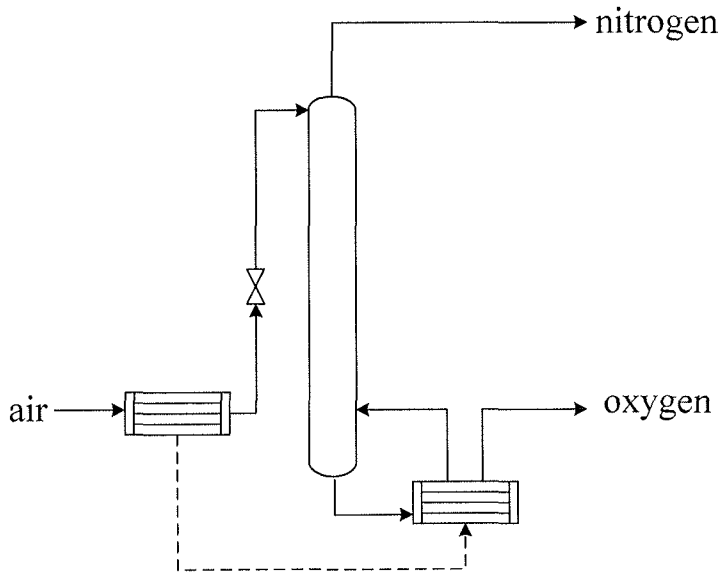
nitrogen
air
oxygen

Fig. 1

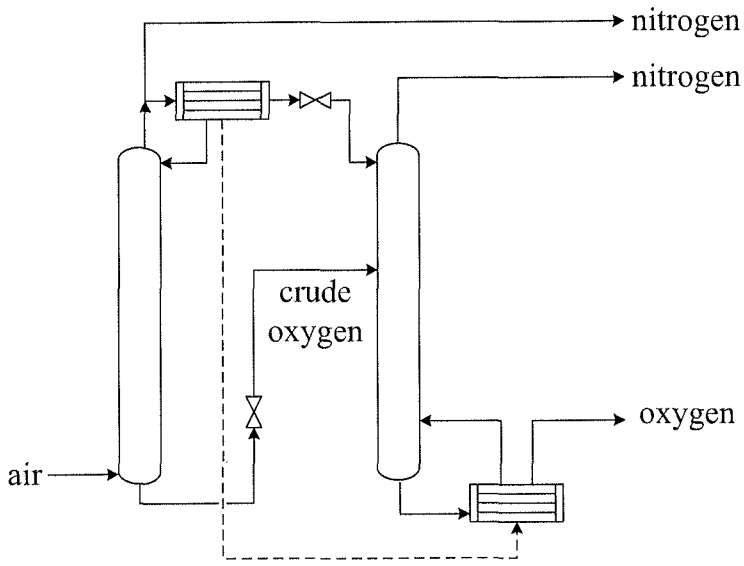
nitrogen
nitrogen
crude
oxygen
oxygen
air

Fig. 2

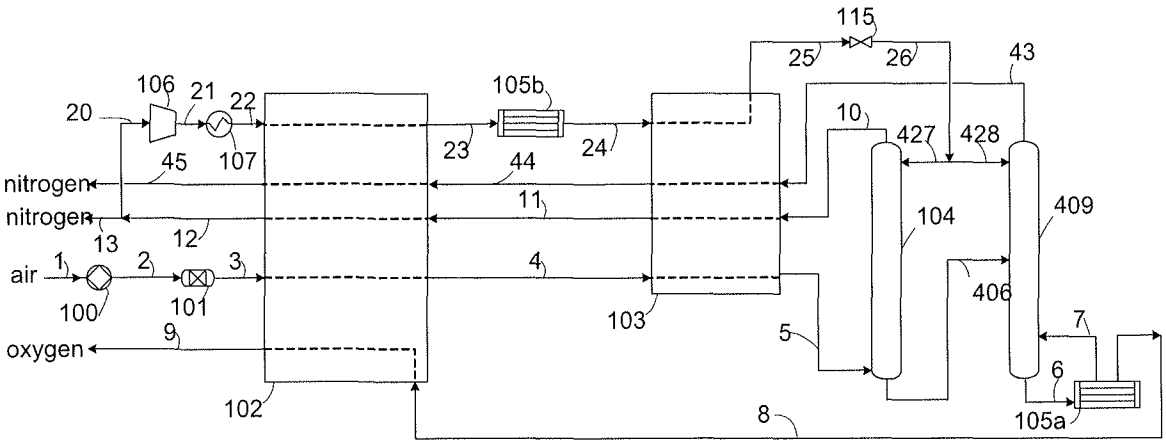
115
25
26
43
106
21
22
105b
20
10
427
428
23
24
45
107
44
nitrogen
11
104
409
nitrogen
13
12
air
1
2
3
4
406
100
101
103
5
7
9
oxygen
6
102
8
105a

Fig. 3

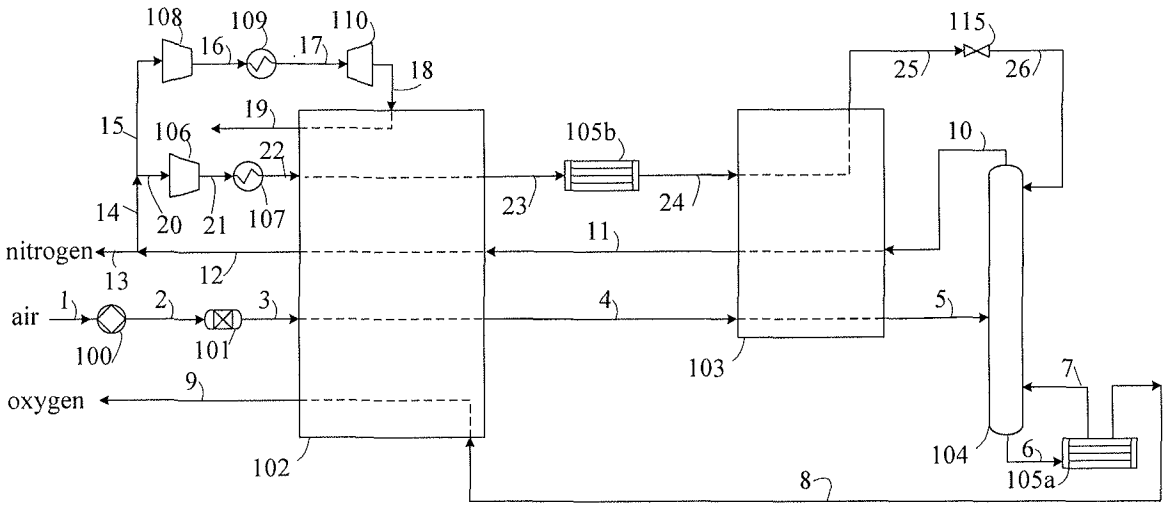
108
109
110
115
16
17
25
26
18
19
15
106
105b
10
22
23
24
14
20
21
107
11
nitrogen
13
12
air
1
2
3
4
5
100
101
103
7
9
oxygen
104
6
102
105a
8

Fig. 4

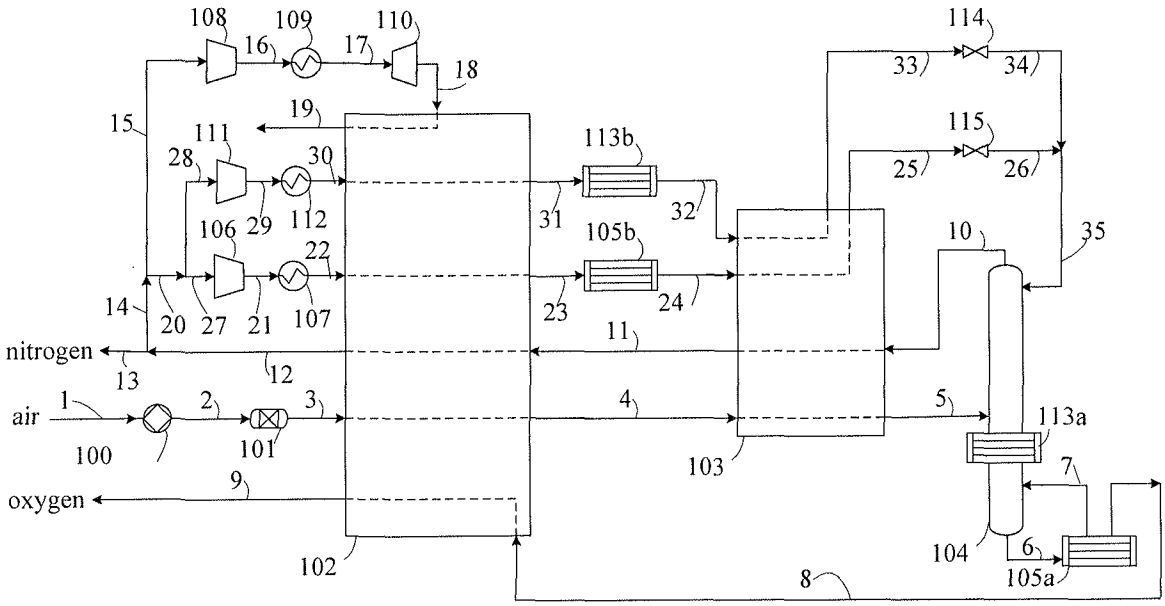
108
109
110
16
17
18
19
15
111
28
30
29
112
106
22
14
20
27
21
107
nitrogen
13
12
air
1
2
3
100
101
oxygen
9
102
113b
105b
31
32
23
24
11
4
103
114
33
34
115
25
26
10
35
5
113a
7
104
6
105a
8

Fig. 5

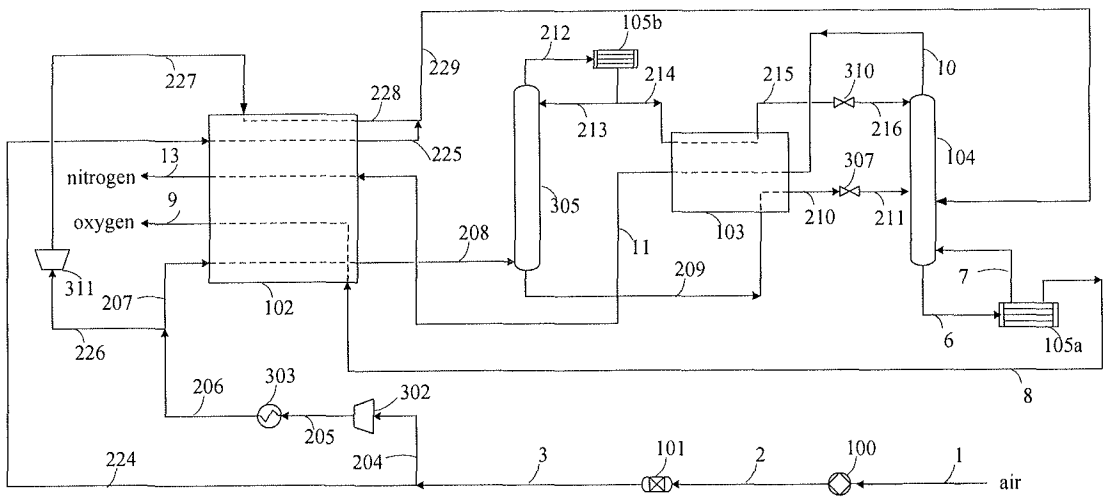
227
228
229
212
105b
214
215
310
10
213
216
225
13
nitrogen
9
oxygen
208
305
307
104
211
210
103
11
209
311
207
102
7
6
105a
226
206
303
302
205
204
8
224
3
101
2
100
1
air

Fig. 6

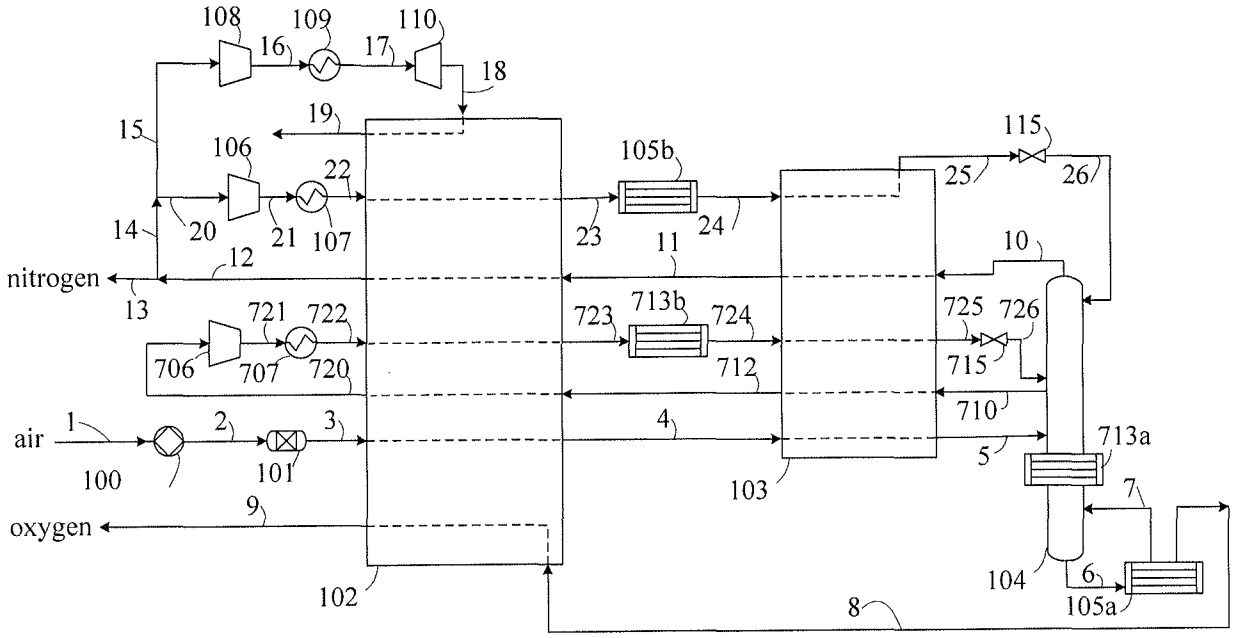
108
109
110
16
17
18
19
15
106
22
105b
115
25
26
14
20
21
107
23
24
11
10
nitrogen
12
13
721
722
723
713b
724
725
726
706
707
720
712
715
710
air
1
2
3
4
713a
5
100
101
103
7
oxygen
9
104
6
102
105a
8

Fig. 7

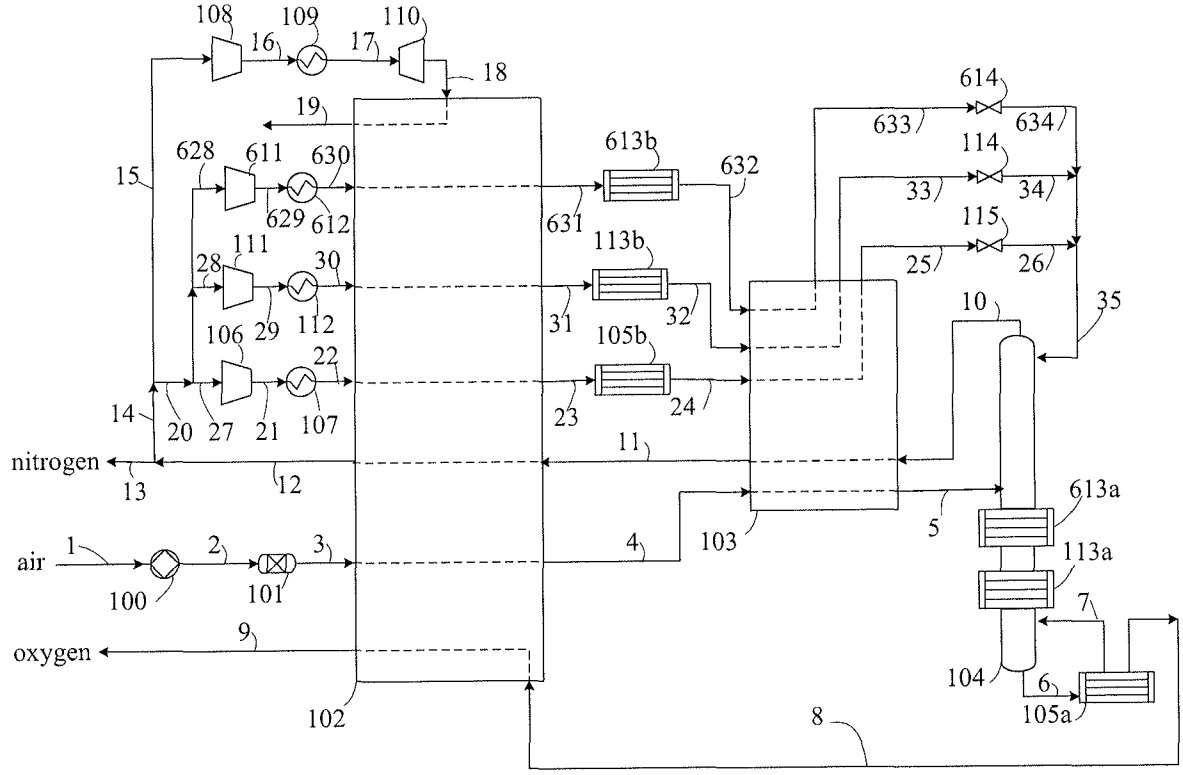
108
109
110
16
17
18
19
614
633
634
628
611
630
613b
632
114
33
34
15
629
612
631
115
25
26
28
111
30
113b
10
35
29
112
31
32
106
105b
22
23
24
14
20
27
21
107
11
nitrogen
12
13
613a
5
103
4
air
1
2
3
113a
100
101
7
9
oxygen
104
6
102
105a
8

Fig. 8

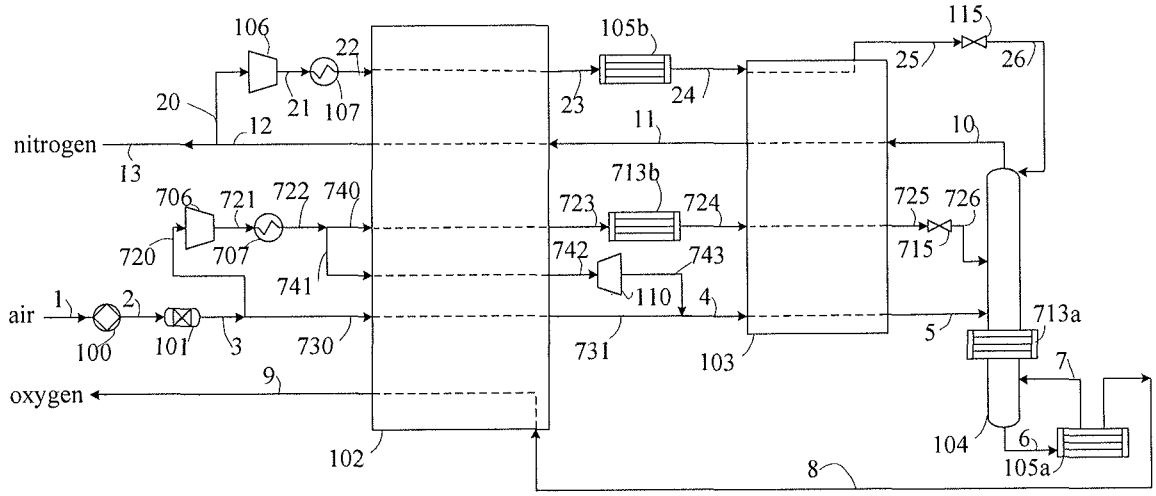

Fig. 9

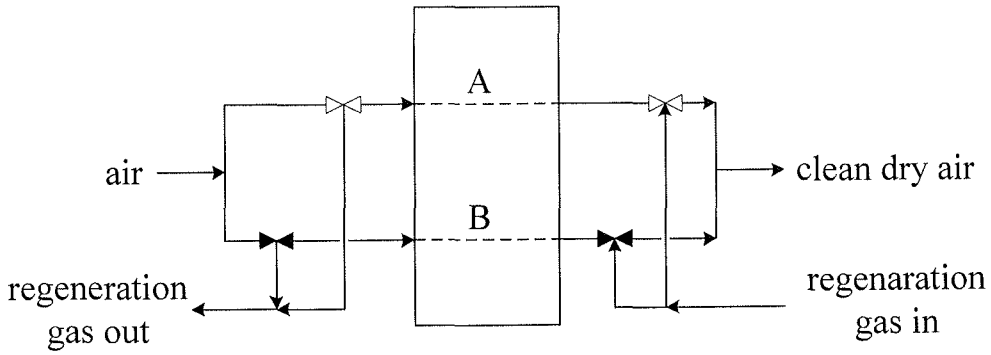

Fig. 10

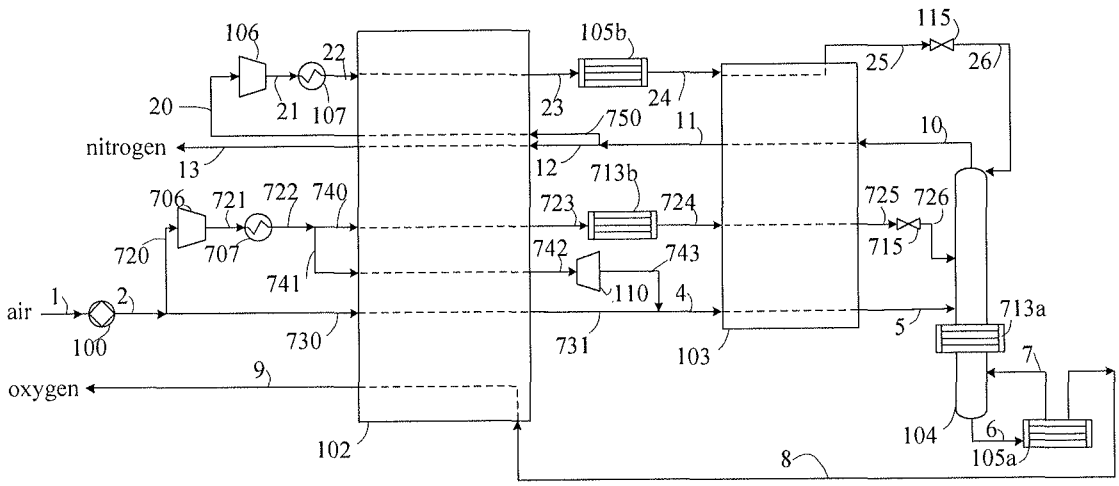

Fig. 11

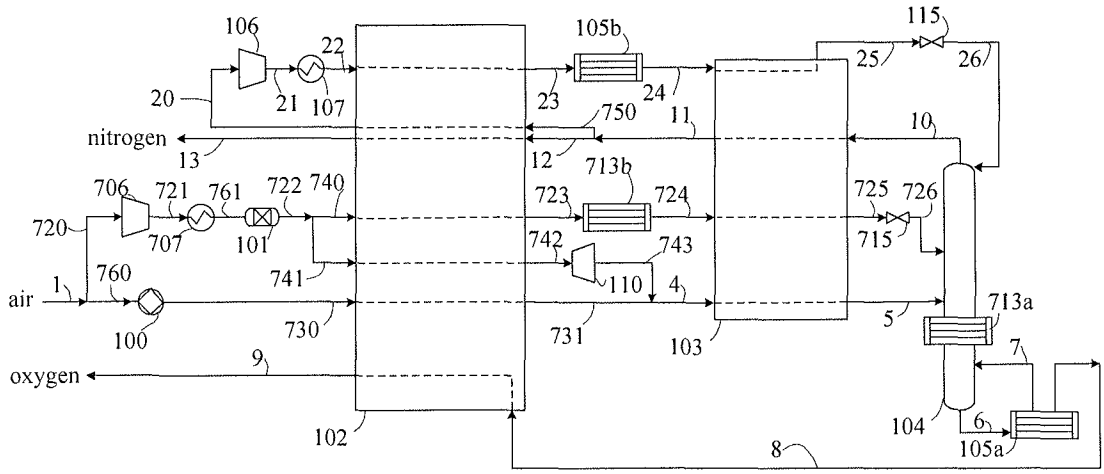
106
22
105b
115
20
21
107
23
24
25
26
nitrogen
13
12
750
11
10
706
721
761
722
740
713b
723
724
725
726
720
707
101
742
743
715
760
741
110
4
air
1
100
730
731
103
5
713a
9
7
oxygen
102
104
6
105a
8

Fig. 12

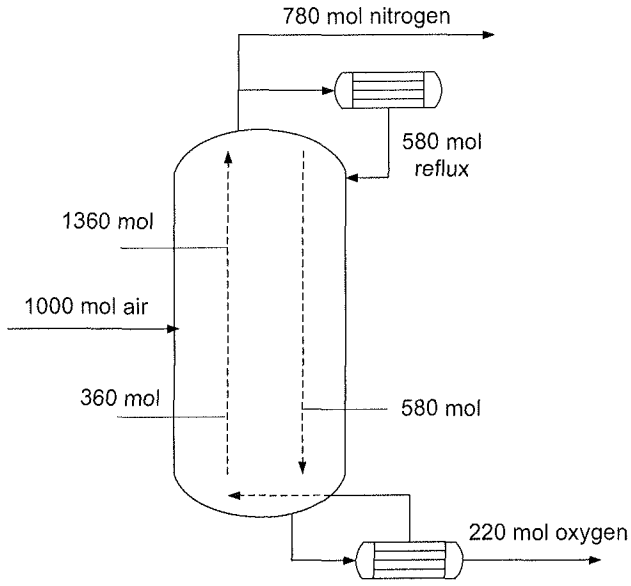
780 mol nitrogen
580 mol
reflux
1360 mol
1000 mol air
360 mol
580 mol
220 mol oxygen

Fig. 13

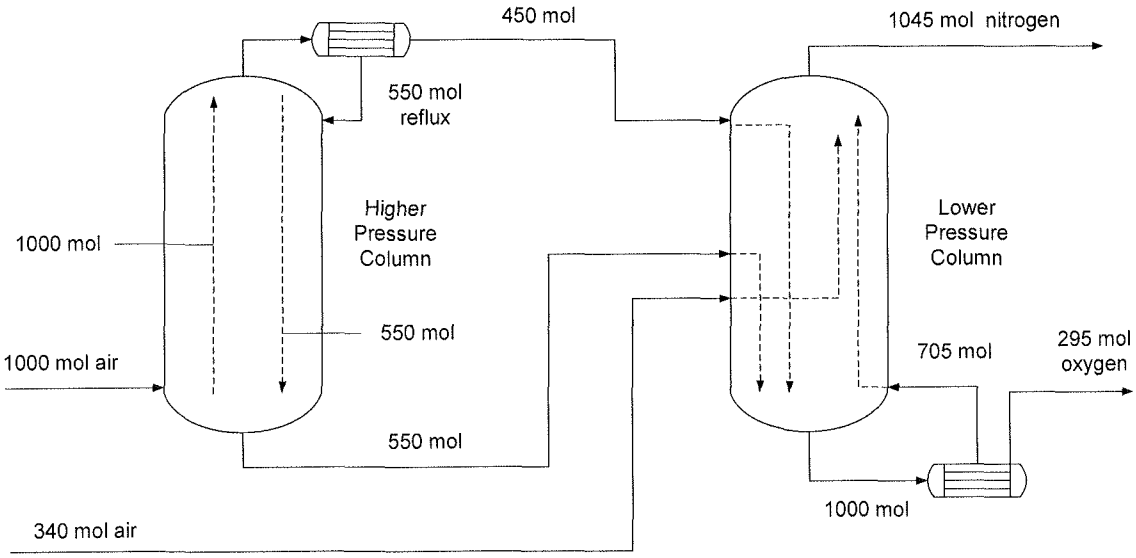
450 mol
1045 mol nitrogen
550 mol
reflux
Higher
Pressure
Column
Lower
Pressure
Column
1000 mol
550 mol
705 mol
295 mol
oxygen
1000 mol air
550 mol
1000 mol
340 mol air

Fig. 14