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(54) Process and apparatus for the separation of air by cryogenic distillation

(57) Nitrogen and/or oxygen are produced by cryogenic distillation of air in an air separation unit comprising at least a medium pressure column (24) and a low pressure column (23) in which air (7,9) is sent to at least the medium pressure column, an oxygen enriched liquid (11) and a nitrogen enriched liquid (12) are removed from the medium pressure column, at least part of the

nitrogen enriched liquid (12) is expanded to produce a two phase nitrogen enriched fluid (15), at least part of the expanded nitrogen enriched fluid containing at least 3,5 % gas, preferably at least 4 % gas is sent into the low pressure column and oxygen rich fluid (16) and nitrogen rich fluid (20) are removed from the low pressure column.

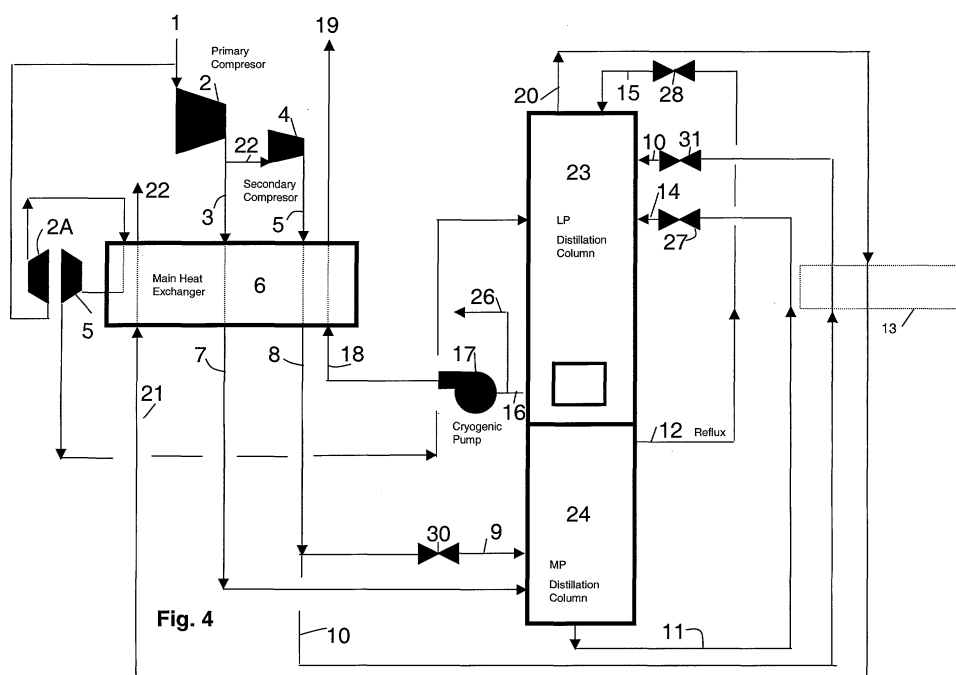


Fig. 4

Description

[0001] This invention relates to a process and apparatus for the separation of air by cryogenic distillation. The process may be used to produce gaseous oxygen, nitrogen, and/or argon.

[0002] All pressures mentioned herein are absolute pressures.

[0003] The percentages of gas and liquid for the reflux fluids and all other fluids given in this document are molar percentages.

[0004] There are two main categories of process cycles, which can be utilized to produce gaseous oxygen under pressure. The first category is known as the classical gas cycle, which utilizes a compressor to pressurize the product gaseous oxygen. The second category is known as the pumping cycle, which utilizes a cryogenic pump to pressurize liquid oxygen, which is then vaporized to produce pressurized product gaseous oxygen. There are two main types of pumping cycle plants; the classical pumping cycle and the "offset knee" cycle.

[0005] In a classical gas cycle, there is a heat exchange that transfers heat from the feed air to the near saturation, low-pressure gaseous oxygen. In this process, the feed air is cooled in a heat exchanger against the gaseous oxygen and nitrogen streams, which are thus superheated. (see US-A-6116052). A standard double column is used with a reboiler condenser (not shown) being used to provide heat transfer between the top gas of the MP column 24 and the bottom liquid of the LP column, thereby providing reboil to the LP column and reflux to the MP column.

[0006] Attention is directed to Figure 1, which describes a typical classical gas cycle plant as taught in the prior art.

[0007] All the feed air 1 is compressed in a compressor (not shown). In order to prevent the loss of efficiency due to the buildup of impurities on cryogenic equipment, and to eliminate any hazardous conditions that could be caused by this buildup of impurities, the compressed feed air 3 is first purified. This step is not indicated in Figure 1, but typically consists of a series of steps which include cooling, adsorption and filtration.

[0008] The air is then divided into two parts 3, part 3 being compressed in booster 2 and is then directed through the main heat exchanger 6.

[0009] Part 4 is compressed in a booster 2A coupled to a turbine which feeds part of the air to the low pressure column 23.

[0010] Within the main heat exchanger 6, product streams at cryogenic temperatures, such as gaseous nitrogen 21 and gaseous oxygen 16 exchange heat with the compressed feed air stream 3. The gaseous oxygen stream 16 is warmed into gaseous oxygen stream 18 for export from the system. Simultaneously, the compressed, gaseous inlet air stream 3 is refrigerated to form stream 7 as it transfers its heat to the gaseous oxygen stream and to the gaseous nitrogen stream.

[0011] The gaseous air stream 7 is either introduced entirely into the Medium Pressure (MP) distillation column 24 as shown in Figure 1 or is split into two streams whereby part of the stream is directed into the MP distillation column and part of the stream is directed into the LP distillation column following expansion in a turbine (not shown).

[0012] This feed air is separated into its basic components in the MP distillation column 24. An oxygen enriched liquid stream 11 is removed from the bottom of the MP column and a nitrogen enriched liquid stream 12 is extracted from the top of the MP distillation column and directed toward a reflux subcooler 13.

[0013] For one skilled in the art, reflux is known to be necessary for mass transfer to occur in any distillation column. "Reflux" in any distillation column is the liquid falling downward through the column. The reflux stream sent to a point in a column must generally have a concentration of heavier components (oxygen in the instant case) which is in equilibrium with the vapor which is rising through the column at that point. At each stage in the distillation column, the composition of the liquid and vapor will come to equilibrium. By adding an essentially oxygen free stream (i.e. reflux stream) to the top of the lower pressure column, the heavy components present in the rising vapor stream are transferred to the descending liquid stream. This yields high concentrations of heavy components at the bottom of the column and low concentrations of heavy components at the top of the column.

[0014] Within the reflux subcooler 13, the oxygen rich stream 11 and the nitrogen rich stream 12 exchange heat with the "nearly pure" gaseous nitrogen stream 20 that is being withdrawn from the top of the LP distillation column 23.

[0015] At one atmosphere of pressure, liquid nitrogen has a saturation temperature of -196°C , and liquid oxygen has a saturation temperature of -183°C . At five atmospheres of pressure, liquid nitrogen has a saturation temperature of -180°C , and liquid oxygen has a saturation temperature of -143°C . Thus, the greater the pressure differential between the MP distillation column (24) and the LP distillation column (23), the greater the degree of subcooling that is available for the reflux stream.

[0016] The gaseous nitrogen 20 that is being withdrawn from the top of the LP distillation column 23 is at a lower pressure than the nitrogen rich reflux stream 12, which means that the reflux line 12 can be subcooled considerably by stream 20. For any air separation unit (ASU) process, it is generally desirable to provide maximum reflux flow to the lower pressure column. It is also generally desirable to have these reflux streams as cold as possible to minimize flashing of the reflux streams and to maximize the distillation effect in the lower pressure column. This is why a reflux subcooler exchanger 13 is typically added to the design.

[0017] Then the subcooled nitrogen enriched stream 15 is introduced into the top of the LP distillation column 23. As the pressure of the medium pressure, subcooled reflux is reduced through a pressure reduction valve, the Joule-Thompson expansion further reduces the temperature and increases the degree of subcooling of the reflux stream. The oxygen enriched stream 11 is also subcooled in the reflux subcooler 13 and introduced into the LP distillation column 23 as stream 14.

[0018] The "nearly pure" nitrogen stream 20 temperature increases slightly in the reflux subcooler due to the heat transfer to the reflux streams 12 and 11. Next this gaseous nitrogen stream 21 passes through the main heat exchanger 6, where it is warmed due to the heat transfer to the feed air stream. It is then exported as low-pressure gaseous nitrogen product 22.

[0019] The other main product of this second distillation process is a "nearly pure" oxygen stream 16 which is withdrawn as gas near the bottom of the LP distillation column 23. This gaseous oxygen is very near its saturation temperature, so it is superheated in the main heat exchanger 6. Since the primary design goal of the classic gas cycle is to produce gaseous oxygen at a useable pressure, the pressure of this stream is increased by means of an oxygen compressor 17. It is then exported as high-pressure gaseous oxygen product 19.

[0020] This has historically been the basic process scheme for most air separation units. The main advantage of this type of process is its simplicity. Typically, the classical gas cycle does not produce unwanted liquid oxygen product, but if so desired, can typically be designed to produce up to approximately 5 % of the feed air as liquid for backup purposes.

[0021] The classical gas cycle will typically yield a very low specific power. In this application, specific power is defined as the total plant electrical utilization divided by the net volume of gaseous oxygen generated. Typically, this criteria is expressed in units of kW (electrical power) divided by Nm^3 (volumetric flowrate). This can be viewed as an indication of overall plant efficiency, with a more efficient plant having lower specific power.

[0022] Thus, the main disadvantage of the classical gas cycle is a higher overall capital equipment cost. Another disadvantage of this cycle is a higher degree of cycle complexity, and associated with this complexity is a higher maintenance cost and a lower reliability. The advantage of this cycle is a generally good specific power.

[0023] In a classical pumping cycle, there is a heat exchanger that transfers heat from the feed air to the liquid oxygen. In this process, the feed air is cooled in a heat exchanger against the liquid oxygen stream, which is thus vaporized. As a means of controlling the throughput, the feed air is compressed then split into two separate streams. The first stream is directed through the heat exchanger, with the other stream being further compressed to an intermediate pressure, and hence adding additional energy required to produce vaporized oxygen. In some cases, this intermediate pressure stream is further split into two separate streams. One of these streams is compressed to a fairly high pressure, as required for the oxygen vaporization (see e.g., US-A-5735142).

[0024] Attention is directed to Figure 2, which describes a typical classical pumping cycle plant as taught in the prior art.

[0025] A standard double column is used with a reboiler condenser (not shown) being used to provide heat transfer between the top gas of the MP column 24 and the bottom liquid of the LP column, thereby providing reboil to the LP column and reflux to the MP column.

[0026] Once the air 1 compressed in compressor (not shown) is adequately purified, as discussed above for Figure 1, it is then split into two separate streams. The first compressed inlet air stream is compressed in booster 2 and then into two, one part 3 being directed through the main heat exchanger 6, with the other stream 22 passing through the secondary booster 4. This second, more highly compressed, compressed inlet air stream 5 is then directed through the main heat exchanger 6, and hence adds any additional heat that may be required for the oxygen vaporization balance. In some cases, this intermediate pressure, compressed inlet air stream 5 is further split into separate streams, with one of these streams being further compressed, as required for energy input to the oxygen vaporization process (see e.g., US-A- 5735142). This step is not indicated on Figure 2.

[0027] Refrigeration is provided by stream 4 which is boosted in 2A and expanded in turbine 5 as described in Figure 1.

[0028] Within the main heat exchanger 6, a liquid product stream at cryogenic temperatures, such as liquid oxygen 18 exchanges heat with the two compressed inlet air streams 3 and (5). Phase change takes place in this oxygen stream and in air stream 5, if their pressures are not supercritical. The liquid oxygen stream 18 is vaporized into a gaseous oxygen stream 19, which is then exported as product for sale. Simultaneously, the compressed, gaseous inlet air streams 7 and 8 transfer their latent and sensible heat to the liquid oxygen stream.

[0029] The liquid air stream 8 is either introduced entirely into the Medium Pressure (MP) distillation column 24 following expansion in a valve or a hydraulic turbine, introduced entirely into the Low Pressure (LP) distillation column 23 following expansion in a valve or a hydraulic turbine, or is split into two streams whereby part of the stream (9) is directed into the MP distillation column and part of the stream (10) is directed into the LP distillation column following expansion steps for each stream in a respective valve or hydraulic turbine. The air stream, if any, sent to the low pressure column is subcooled before expansion in the reflux subcooler 13.

[0030] Gaseous stream 7 is directed to the MP distillation column. This air is separated into its basic components in the MP distillation column (24). The vapor, which is richer in volatile components, which in this case would be the nitrogen component, rises to the top of the distillation column. The liquid, which is richer in less volatile components, which in this case would be the oxygen component, falls to the base of the distillation column. An oxygen enriched stream 11 and a nitrogen enriched stream 12 are extracted from the MP distillation column 24 as described in Claim 1 and directed toward a reflux subcooler 13. The function served by, and the benefits derived from the reflux subcooler are discussed above with respect to Figure 1.

[0031] Then the subcooled liquid reflux stream 15 is introduced into the top of the LP distillation column 23. The oxygen rich bottom stream 11 is also subcooled in the reflux subcooler 13 and introduced into the LP distillation column 23 as liquid stream 14.

[0032] After this second distillation process, a "nearly pure" nitrogen stream 20 is withdrawn from the top of the LP distillation column 23. It then passes through the reflux subcooler 13, where the temperature of the stream increases slightly due to the heat transfer to the streams 12 and 11. Next this gaseous nitrogen stream 21 passes through the main heat exchanger 6. It is then exported as low-pressure gaseous nitrogen product 22.

[0033] The other main product of this second distillation process is an oxygen stream 16 which is withdrawn at the base of the LP distillation column 23 containing at least 70 mol. % oxygen. If so desired, LP liquid oxygen can be withdrawn from the cycle at this point 26. Ordinarily, the classic pumping cycle produces little if any liquid oxygen product, and only withdraws liquid oxygen to place in storage for backup purposes. Since the primary design goal of the classic pumping cycle is to produce relatively high-pressure gaseous oxygen, the pressure of this low-pressure liquid is increased significantly by means of a cryogenic pump 17. This high-pressure liquid oxygen stream 18 then passes through the main heat exchanger 6, where it is vaporized due to the heat transfer to the inlet air streams. It is then exported as high-pressure gaseous oxygen product 19.

[0034] The main advantage of this type of process is its ability to produce pressurized oxygen without an oxygen compressor. Another advantage is its operational flexibility in terms of liquid production. The classical pumping cycle generally has no unwanted liquid oxygen product at all. In this application, unwanted liquid oxygen product is defined as the amount of liquid product that is produced by a given process, as a function of the design itself. Whether or not such liquid product is desirable, this amount of liquid product cannot be avoided, and is simply a necessary byproduct of that particular chosen process. The classical pumping cycle also has a generally good specific power.

[0035] Thus, the classical pumping cycle has no pronounced disadvantages or advantages. This cycle will have a higher overall capital equipment cost than an offset knee cycle (see below), yet will have a lower overall capital equipment cost than a classical gas cycle. This cycle will have a higher degree of cycle complexity than an offset knee cycle (see below), yet will have a lower degree of cycle complexity than a classical gas cycle. This cycle will have a higher specific power requirement than a GOK cycle (see below), yet will have a lower specific power requirement than a classical gas cycle.

[0036] In the pumping plant process commonly named the offset knee cycle, again there is a heat exchanger that transfers heat from the feed air to the liquid oxygen. However, in this cycle, all the feed air is compressed to the pressure required to vaporize the oxygen, rather than just part of the stream, and also to a lower pressure than in the cycle above. Whereas in a classical pumping cycle, a second air booster may typically operate at 21 bar or less, in the GOK cycle, the air booster or last stage of the main compressor may typically operate at between 21 bar and 41 bar. (See e.g., US-A-5329776).

[0037] Attention is directed to Figure 3, which describes a typical offset knee cycle plant as taught in the prior art.

[0038] Once the inlet air 1 is compressed in compressor 2 to a pressure considerably higher than the medium pressure and generally between 21 and 41 bar, it is then purified, as discussed above for Figure 1. This high pressure, compressed inlet air stream 3 is directed through the main heat exchanger 6. Within the main heat exchanger, this high pressure stream is split into two separate streams. The first high pressure stream 7 continues through the heat exchanger, and the other high pressure, compressed inlet air stream 4 is removed from an intermediate point of the heat exchanger and directed toward an expander 5. The amount of high pressure air 4 that is withdrawn is determined by the requirement for the oxygen vaporization and refrigeration balance. Whereas in a classical pumping cycle, the air booster (see 4 in Figure 2) may typically operate at between 5.5 and 21 bar, in the offset knee cycle, the air booster or the final stage of compressor 2 may typically operate at above 21 bar (see e.g., US-A-5329776).

[0039] Within the main heat exchanger 6, product streams at cryogenic temperatures, such as gaseous nitrogen 21 and liquid oxygen 18 exchange heat with the compressed inlet air streams 3,5. Phase changes may take place in streams 18 and 3 depending on whether the pressures are supercritical or not. The gaseous nitrogen stream 21 is warmed and the liquid oxygen stream 18 is vaporized into a gaseous oxygen stream 19, both of which may then be exported as products for sale, or used to precool the air before entering exchanger 6. Simultaneously, the compressed, gaseous inlet air stream is cooled 7 as it transfers its latent and sensible heat to the liquid nitrogen and liquid oxygen streams.

[0040] The gaseous air stream 7 is either introduced entirely into the Medium Pressure (MP) distillation column 24,

introduced entirely into the Low Pressure (LP) distillation column 23, or is split into two streams as shown whereby part of the stream 9 is directed into the MP distillation column and part of the stream 10 is directed into the LP distillation column as reflux, following subcooling of the stream 10 in subcooler 13. As the high pressure, compressed inlet air stream 4 that had been redirected to the expander 5, exits the expander at a much lower pressure, it will either be a

[0041] This gaseous or two phase air is separated into its basic components in the MP distillation column 24. An oxygen enriched bottom stream 11 is removed from the bottom of the medium pressure column and a nitrogen enriched reflux stream 12 is extracted from the top of the MP distillation column and both are directed toward a reflux subcooler (13). The function served by, and the benefits derived from, the reflux subcooler are discussed above with respect to Figure 1.

[0042] Then the subcooled nitrogen enriched stream 15 is introduced into the LP distillation column 23. The oxygen enriched bottom stream 11 is also subcooled in the reflux subcooler 13 and this subcooled stream 14 introduced into the LP distillation column 23.

[0043] After the separation of the reflux streams in the low pressure column, a "nearly pure" nitrogen stream 20 is withdrawn from the top of the LP distillation column 23. It then passes through the reflux subcooler 13, where the temperature of the stream increases slightly due to the heat transfer to the reflux streams 11 and 12. Next this gaseous nitrogen stream 21 passes through the main heat exchanger 6, where it is warmed due to the heat transfer to the inlet air stream. It is then exported as low-pressure gaseous nitrogen stream 22.

[0044] The other main product of this second distillation process is a "nearly pure" oxygen stream 16 which is withdrawn at the base of the LP distillation column 23. If so desired, LP liquid oxygen can be withdrawn from the cycle at this point 26. A typical offset knee cycle exports approximately 20 % to 25 % of the total oxygen production in the form of liquid oxygen product. The primary design goal of this cycle is to produce liquid, and the pressure of this low pressure liquid is increased significantly by means of a cryogenic pump 17. This high-pressure liquid oxygen stream 18 then passes through the main heat exchanger 6, where it is vaporized due to the heat transfer to the inlet air stream. It is then exported as high-pressure gaseous oxygen product 19.

[0045] Some of the advantages of this type of process are its simplicity and its lower capital investment. The main disadvantage of this cycle is the relatively high specific power compared to the classical pumping cycle. This cycle requires only one air compressor and one expander. Lower operating and maintenance costs are also associated with this decreased cycle complexity.

[0046] A disadvantage of this type of process is the reduced operational flexibility in terms of liquid production. This is due to the significant amount of unwanted liquid oxygen product that is produced. Depending on the process parameters of the particular cycle, a typical offset plant will produce between 5 % to 40 % of the gaseous oxygen produced unwanted liquid oxygen product. In the current state of the art, it is impossible to design a typical offset knee plant that produces little or no unwanted liquid oxygen product.

[0047] According to the present invention, there is provided a process for producing nitrogen and/ or oxygen by cryogenic distillation of air in an air separation unit comprising at least a medium pressure column and a low pressure column comprising the steps of

- a) sending cooled compressed gaseous air to at least the medium pressure column
- b) removing an oxygen enriched liquid and a nitrogen enriched liquid from the medium pressure column
- c) expanding at least part of the nitrogen enriched liquid to produce a nitrogen enriched fluid and sending at least part of the expanded nitrogen enriched fluid into the low pressure column
- d) removing oxygen rich fluid and nitrogen rich fluid from the low pressure column

characterized in that at least part of the expanded nitrogen enriched liquid is sent from the medium pressure column to the low pressure column without undergoing a cooling step prior to expansion and/or the nitrogen enriched fluid sent into the low pressure column contains at least 3,5 % gas, preferably at least 4 %, more preferably at least 5 %, still more preferably at least 6% gas.

[0048] According to other optional features, the process may comprise expanding at least part of the oxygen enriched liquid to form an expanded oxygen enriched fluid and sending at least part of the expanded oxygen enriched fluid to the low pressure column wherein the oxygen enriched fluid sent into the low pressure column contains at least 13 %, preferably at least 13,5 %, more preferably at least 14,5%, still more preferably at least 16% gas.

[0049] Optionally:

- at least part of the expanded oxygen enriched liquid is sent to the low pressure column without undergoing a cooling step prior to expansion.
- part of the oxygen enriched liquid to be expanded is cooled by heat exchange with nitrogen rich fluid from the low pressure column and part of the oxygen enriched liquid to be expanded is not cooled by heat exchange with

nitrogen rich fluid from the low pressure column before being sent to the low pressure column and/or part of the nitrogen enriched liquid to be expanded is cooled by heat exchange with nitrogen rich fluid from the low pressure column and part of the nitrogen enriched liquid to be expanded is not cooled by heat exchange with nitrogen rich fluid from the low pressure column before being sent to the low pressure column.

- none of the oxygen enriched liquid is cooled by heat exchange with nitrogen rich fluid from the low pressure column before being sent to the low pressure column and /or none of the nitrogen enriched liquid is cooled by heat exchange with nitrogen rich fluid from the low pressure column before being sent to the low pressure column.
- a portion of the cooled compressed air is used to vaporize a liquid removed from the low pressure column or the high pressure column, at least part of the portion of the cold compressed air is sent to the low pressure column in liquid form following a subcooling step and an expansion step.
- at least 1,6 %, preferably at least 1,7 %, still more preferably at least 2% and/or at most 15%, preferably at most 5% of the at least part of the portion of cold compressed air sent to the low pressure column is in gaseous form.
- nitrogen enriched gas is removed from the top of the low pressure column and exchanges heat with the at least part of the portion of the cooled compressed air during the subcooling step.
- all of the feed air is compressed to a high pressure, a portion of the air is used to vaporize a liquid removed from the low pressure column or the high pressure column and the rest of the air is expanded to the pressure of the medium pressure column in a turbine and is sent to the medium pressure column in at least mostly gaseous form.
- at least one liquid is withdrawn from a column of the unit as a final product.

According to a further aspect of the invention, there is provided an installation for producing nitrogen and/or oxygen by cryogenic distillation of air in an air separation unit comprising at least a medium pressure column and a low pressure column comprising :

- a) means for sending cooled compressed gaseous air to at least the medium pressure column
- b) means for removing an oxygen enriched liquid from the medium pressure column and means for removing a nitrogen enriched liquid from the medium pressure column
- c) expanding means for expanding at least part of the nitrogen enriched liquid to produce a nitrogen enriched fluid and sending at least part of the expanded nitrogen enriched fluid into the low pressure column
- d) means for removing oxygen rich fluid and nitrogen rich fluid from the low pressure column

characterized in that there are no means for cooling at least part of the nitrogen enriched liquid upstream of the nitrogen enriched liquid expanding means, preferably no means for cooling the nitrogen enriched liquid upstream of the nitrogen enriched liquid expanding means.

[0050] Thus all or part of the nitrogen enriched liquid is sent directly from the medium pressure column to the expanding means. The nitrogen enriched liquid may be removed from the top or an intermediate region of the medium pressure column.

[0051] Preferably the installation comprises means for sending at least part of the oxygen enriched liquid directly or indirectly to the low pressure column and expanding means for expanding the oxygen enriched liquid upstream of the low pressure column.

[0052] However there may be no means for cooling at least part of the oxygen enriched liquid upstream of the oxygen enriched liquid expanding means, preferably no means for cooling the oxygen enriched liquid upstream of the oxygen enriched liquid expanding means. Thus all or part of the oxygen enriched liquid is sent directly from the medium pressure column to the expanding means.

[0053] Preferably the installation comprises

- means for removing a liquid stream from a column of the air separation unit and means for vaporizing at least part of the liquid stream, preferably upstream of a pressurization means.
- means for vaporizing at least part of the liquid stream by heat exchange with an air stream, means for subcooling at least part of the air stream by heat exchange with a nitrogen enriched stream from the low pressure column, means for expanding the subcooled air stream and means for sending the expanded subcooled air stream to the low pressure column.
- a main heat exchanger, means for sending all the feed air for the air separation unit and at least part of the liquid stream to be vaporised to the main heat exchanger, means for sending the air stream to be subcooled to the main heat exchanger and means for removing the subcooled air stream from the main heat exchanger upstream of the means for expanding the subcooled air stream.
- a subcooler and means for sending only the air stream and at least one nitrogen stream from the low pressure column to the subcooler.
- means for compressing all the feed air to a high pressure, means for expanding part of the air to the pressure of the medium pressure column, means for sending the expanded air to the medium pressure column, means for

sending the rest of the air to the low pressure column and possibly the medium pressure column following expansion and liquefaction.

[0054] The unit may comprise an intermediate pressure column, means for feeding the intermediate pressure column with oxygen enriched liquid from the medium pressure column and means for feeding fluids from the intermediate pressure column to the low pressure column.

[0055] To understand the nature and objects of the present invention, reference should be had to the following detailed description, taken in conjunction with the accompanying drawings, in which :

Figure 1 is a schematic illustration of an apparatus for the production of gaseous oxygen utilizing the classic gas cycle, according to the prior art.

Figure 2 is a schematic illustration of an apparatus for the production of gaseous oxygen utilizing the classic pumping cycle, according to the prior art.

Figure 3 is a schematic illustration of an apparatus for the production of gaseous oxygen, utilizing the offset knee cycle, according to the prior art.

Figure 4 is a schematic illustration of an apparatus for the production of gaseous oxygen according to this invention, utilizing the classic pumping cycle.

Figure 5 is a schematic illustration of an apparatus for the production of gaseous oxygen according to this invention, utilizing the offset knee cycle.

Figure 6 is a diagram, obtained by calculation, showing how the relative oxygen recovery, according to this invention, varies as a function of the relative reflux subcooler duty.

Figure 7 is a schematic illustration of an apparatus for the production of gaseous oxygen according to this invention, utilizing the classic pumping cycle.

Figure 8 is a schematic illustration of an apparatus for the production of gaseous oxygen according to this invention, utilizing the offset knee cycle.

[0056] The invention can be used in a variety of cycles, for a variety of productions of liquids and gases, and at a variety of temperatures and pressures. The following explanations are examples of some of the uses of this invention, and are not meant to be limiting in any way.

[0057] First the invention, illustrated by way of example, in Figure 4 using the classical pumping cycle will be discussed.

[0058] Once the compressed inlet air 1 is purified, it is divided into two streams. One stream is boosted in booster 2A and then expanded in turbine 5 before being sent to the low pressure column. Other additional or alternative means of providing refrigeration may be envisaged, such as a Claude turbine.

[0059] The rest of the air is compressed in booster 2 to the pressure of the medium pressure column (at least 5,5 bar) and then split into two separate streams 3,22. Alternatively, two separate compressors may be used without splitting the inlet air into two streams. The first compressed inlet air stream 3 is directed through the main heat exchanger 6, with the other stream 22 passing through the secondary compressor 4. This second, more highly compressed inlet air stream 5 is then directed through the main heat exchanger 6, and hence adds any additional heat that may be required for the oxygen vaporization balance. In some cases, this intermediate pressure, compressed inlet air stream 5 is further split into separate streams, with one of these streams being further compressed, as required for energy input to the oxygen vaporization process.

[0060] Within the main heat exchanger 6, a liquid stream at cryogenic temperatures, such as liquid oxygen 18 exchanges heat with the two compressed inlet air streams 3 and 5. Phase changes may takes place in stream 5 if the pressure is subcritical. The liquid oxygen stream 18 is vaporized into a gaseous oxygen stream 19, which is then exported as product for sale. Simultaneously, the compressed, gaseous inlet air stream is cooled 8 as it transfers its latent and sensible heat to the liquid oxygen stream.

[0061] The air stream 8 may be introduced entirely into the Medium Pressure (MP) distillation column 24 in mainly liquid form, introduced entirely into the Low Pressure (LP) distillation column 23 in mainly liquid form, or is split into two streams whereby part of the stream 9 is directed into the MP distillation column and part of the stream 10 is directed into the LP distillation column both in mainly liquid form as shown. The compressed stream 10, typically between 40 et 60 % of stream 8, is subcooled in reflux subcooler 13 against gaseous nitrogen 20 and then passes through a pressure reduction valve 31 before entering the low pressure column 23 containing at least 1,6 %, preferably at least 1,7 % and/or at most 15 %, preferably at most 5 % gas. It is important to avoid introducing too much air as flash gas.

[0062] The gaseous and mainly liquid air 25, 9 is separated into its basic components in the MP distillation column 24. An oxygen enriched liquid stream 11 is withdrawn from the bottom of the MP column 24 and a nitrogen enriched liquid stream 12 is extracted from the top of the MP distillation column. These streams are conveyed to the LP column by means of an operating pressure differential across a valve or a dense fluid expander between the HP and LP column.

[0063] In the prior art there was a reflux subcooler between the LP and MP distillation columns so that the oxygen rich 11 stream and nitrogen reflux stream 12 could be cooled by the nearly pure nitrogen stream 20 from the low pressure column. However, there are many advantages of modifying the reflux subcooler as described herein so that only air stream 10 is subcooled and the refrigeration conveyed by the stream 20 is transferred to the air stream only so that the air stream is colder than that of prior art. Alternatively or additionally, the internal surface area of the reflux subcooler can be reduced and/or only part of the at least one of the reflux liquids 10,11,12 are subcooled (not shown in Figure 4).

[0064] The subcooler 13 can form part of the heat exchanger 6.

[0065] In the preferred embodiment the oxygen rich stream 11 passes through a pressure reduction valve 27 upstream of the LP column and the nitrogen rich stream 12 also passes through a pressure reduction valve 28 or other such apparatuses or devices known to one skilled in the art. The reflux stream 15, which has not been cooled by any step other than the expansion step in valve 28, is introduced into the LP distillation column 23 containing substantially 17 % gas. The oxygen rich bottom stream 11, which has not been cooled by any step other than the expansion step in valve 27, is introduced into the LP distillation column 23 at an intermediate level containing substantially 17 % gas.

[0066] After the distillation of the reflux streams 10, 11, 12, a "nearly pure" nitrogen stream 20 is withdrawn from the top of the LP distillation column 23 and cools the air stream 8 upstream of valve 29. The expanded air is then sent to the low pressure column 23 in at least mostly liquid form. Next this gaseous nitrogen stream 21 passes through the main heat exchanger 6. It is then exported as low-pressure gaseous nitrogen product 22.

[0067] The other main product of this second distillation process is a oxygen stream 16 containing at least 70 mol. % oxygen which is withdrawn at the base of the LP distillation column 23. If so desired, LP liquid oxygen 26 can be withdrawn from the cycle at this point as a final product. Ordinarily, the classic pumping cycle produces little if any liquid oxygen product, and only withdraws liquid oxygen to place in storage for backup purposes. Since the primary design goal of the classic pumping cycle is to produce relatively high-pressure gaseous oxygen, the pressure of this low-pressure liquid is increased significantly by means of a cryogenic pump 17. This high-pressure liquid oxygen stream 18 then passes through the main heat exchanger 6, where it is vaporized due to the heat transfer to the inlet air streams. It is then exported as high-pressure gaseous oxygen product 19.

[0068] Now the invention, illustrated by way of example, in Figure 5 using the offset knee cycle will be discussed. First, the inlet air purification phase is typical and common to all cryogenic air separation systems, and is therefore not indicated on Figure 5. The inlet air enters the cycle at ambient conditions. This inlet air is compressed in the main air compressor to a pressure higher than the medium pressure and then purified. The compressed air passes through a series of intercoolers, aftercoolers and/or a chilling system cooled to reduce the water vapor in the process air (not shown). The chilling can be done by either a refrigeration system or a direct contact aftercooler, which exchanges heat between the warm inlet air and water which is in turn chilled by gaseous nitrogen which is produced in the air separation cycle. Then the pressurized air passes through an adsorption unit, which removes impurities from the air. These adsorbers can be of the horizontal bed or radial bed design, and typically contain (at least) two types of adsorbents. One adsorbent, typically activated alumina, will dry the air and simultaneously remove any acids present. The other adsorbent, typically a molecular sieve, will remove carbon dioxide, methane and some of the other hydrocarbons which are present. These adsorbers are typically regenerated on-line, and thus (at least) two trains will be required for continuous operation. Finally, the inlet air is passed through a particle filter which is located either inside of or immediately after the adsorber vessels and used to remove fine dust particles and any other particulate contaminants. The pressurized air typically leaves this system at a pressure of approximately 15 to 30 bar, and a temperature of 15 to 30°C.

[0069] Once the inlet air has been pressurized and adequately purified, it passes through another compressor 2. Often referred to as booster compressor, this compressor typically raises the inlet air pressure to approximately 20 to 30 bar (intermediate pressure), and raises the temperature to approximately 35 to 50°C. This intermediate pressure, compressed inlet air stream (3) is then directed through the main heat exchanger 6. For air separation applications, the main heat exchanger is typically of brazed aluminum construction but may also be a shell in tube type or other such exchangers known to one skilled in the art, and utilizes a countercurrent flow. Within the main heat exchanger, this intermediate pressure stream is split into two separate streams. The first intermediate pressure stream 7 continues through the heat exchanger. Approximately 15 to 30 % of the inlet air mass flowrate flows through this stream 7, which provides the heat required to vaporize the high-pressure liquid oxygen stream 18.

[0070] The other intermediate pressure, compressed inlet air stream 4 is removed from an intermediate point of the heat exchanger and directed toward an expander 5. Alternatively, separate streams may be used with or without separate compressors, rather than splitting the compressed air into two streams. The amount of intermediate pressure air that is withdrawn 4 is determined by the requirement for the oxygen vaporization balance. Approximately 70 to 85 % of the inlet air mass flowrate flows through this stream 4, from which the booster 2 consumes approximately 95 % of the power generated by the associated expander 5. The process air 25 leaves the expander 5 with a pressure of approximately 4.5 to 6.5 bar, and a temperature of approximately -170°C to - 175°C. The process air leaving the expander 5 may be comprised of a two-phase flow, of which approximately 5 to 15 % is vapor phase or may be entirely

gaseous (See e.g. US-A-5329776).

[0071] Within the main heat exchanger 6, product streams are present at cryogenic temperatures. The gaseous nitrogen stream 21 has a pressure of approximately 1.2 to 2 bar, and a temperature of approximately -190 to -193°C. The liquid oxygen stream 18 has a pressure which can range from 20 to 80 bar, and a temperature of approximately -170 to -178°C. These streams exchange heat with the compressed inlet air stream 3. Phase changes may take place in stream 3. The gaseous nitrogen stream 22 is warmed to a temperature of approximately 10 to 40°C at the warm end of exchanger 6. The liquid oxygen stream 18 is vaporized into a gaseous oxygen stream 19, which typically has a temperature of approximately 10 to 40°C at the warm end of exchanger 6. Both of these streams are then exported as products for sale. Simultaneously, the compressed gaseous inlet air stream is cooled 7 as it transfers its latent heat to the liquid oxygen stream. This liquefied process air stream typically has a pressure of approximately 20 to 30 bar, and a temperature of approximately -185 to -191°C.

[0072] The intermediate pressure air stream 7 as shown is at least directed to the Low Pressure (LP) distillation column 23, now as stream 10 as required to maintain optimum reflux ratios in the lower sections of the MP and LP distillation columns 23 and 24. As shown it may be split into two streams with one stream 10 introduced into the LP distillation column 23 and the rest 9 to the MP column. Otherwise it may be sent in its entirety to the MP column 24. At least 40% 10 of the stream 7 is sent to the low pressure column containing at least 1,6 %, preferably at least 1,7 % and/or at most 15%, preferably at most 5 %. Whatever the proportion of the air stream 7 sent to column 23 is (less than or equal to 100%), the stream 10 contains at least 1,6 %, preferably at least 1,7 % and/or at most 15%, preferably at most 5% gas at the point of injection into column 23. The compressed stream 10 is first subcooled in reflux subcooler 13 and then passes through a pressure reduction valve 31 before entering the low pressure column 23. Stream 10 is the only stream which exchanges heat with stream 20 upstream of the exchanger 6. The two-phase or gaseous process air stream leaving the expander 5 is directed to the MP distillation column 24.

[0073] This liquid and gaseous air 9, 25 is separated into its basic components in the MP distillation column 24. The MP distillation column typically operates at a pressure that ranges from 4.5 bar to 6.5 bar but may operate at higher pressures.

[0074] An oxygen enriched liquid stream 11 is removed from the bottom of the MP column and a nitrogen rich reflux stream 12 is extracted from the top of the MP distillation column 24 and directed toward the LP distillation column 23 as reflux streams. These streams are conveyed to the LP column by means of an operating pressure differential across a valve or dense fluid expander 27, 28 between the HP column and the LP column. The oxygen rich bottom stream 11 has a pressure of approximately 4.5 to 6.5 bar, a temperature of approximately -170 to -175°C, and a composition of approximately 61.3 % nitrogen, 37.4 % oxygen, and 1.3% argon (mole fraction), preferably containing between 25 and 50 % oxygen. The nitrogen rich reflux stream 12 has a pressure of approximately 4.5 to 6.5 bar, a temperature of approximately -175 to -180°C, and a composition of typically > 99 % nitrogen. The oxygen enriched stream 11 passes through a pressure reduction valve 27, dense fluid expander, or other such devices or apparatuses known to one skilled in the art for reducing pressure, after which the oxygen enriched stream 14 pressure is approximately 1.2 to 2 bar and the temperature is approximately -185 to -190°C containing substantially 17 % gas. The nitrogen rich stream 12 also passes through a pressure reduction valve 28, dense fluid expander or other such devices or apparatus known to one skilled in the art for reducing pressure, after which the reflux stream 15 pressure is approximately 1.2 to 2 bar and the temperature is approximately -190 to -193°C containing substantially 17% gas. As the pressure of the reflux is reduced through a pressure reduction valve, the Joule-Thompson expansion further cools the reflux stream.

[0075] It was previously considered essential to have a subcooler exchanger at this point in the cycle to subcool all the reflux fluids (oxygen enriched, nitrogen enriched and air). This subcooling heat exchange process results in a higher overall cycle efficiency, along with the necessary production of some unwanted liquid oxygen product. This invention, however, takes the step of eliminating this reflux subcooler or reducing its size. This cycle change which has a small impact on cycle efficiency, reduces the capital cost of the plant, decreases the mechanical complexity of the plant, and has the desirable result of reducing or eliminating the generation of unwanted liquid oxygen product by the plant.

[0076] Figure 5 uses a subcooler only to cool the feed air stream 10. It is also possible to subcool only part of stream 10. The subcooler 13 can form part of the heat exchanger 6.

[0077] In an alternative embodiment, if the internal surface area of the reflux subcooler were to be gradually reduced, then the amount of subcooling that the liquid reflux stream 12 would achieve is reduced accordingly. This would result in a reflux stream 12 that is closer to its saturation temperature entering the LP distillation column (23). Thus, this reflux stream 12 will experience a greater degree of flashing upon entry into the LP distillation column 23, with less liquid reflux available to cascade downward through the LP distillation column 23 and thereby aid in the distillation effect of the oxygen. In this embodiment, the reflux stream 12 entering the LP distillation column is flashing significantly, resulting in a vapor fraction of 17.35 %, and hence only 82.65 % of the incoming reflux being liquid phase. This reduces the overall efficiency of the cycle, and reduces the total oxygen recovery, as depicted in Figure 5.

[0078] As the internal surface area of the reflux subcooler 13 is gradually reduced, or ultimately eliminated all together,

much of the heat transfer duty that had been provided by this reflux subcooler 13 will be transferred to the main heat exchanger 6. When a reflux subcooler was introduced into this preferred embodiment, as would be anticipated by the prior art, the reflux subcooler transferred approximately 1.05×10^6 kcal/hr of heat, while the main heat exchanger transferred approximately 1.76×10^7 kcal/hr of heat. Thus, the main heat exchanger had approximately 17 times the duty of the reflux subcooler. When this reflux subcooler was removed from the preferred embodiment, and the cycle output was held constant, the main heat exchanger now transferred approximately 1.79×10^7 kcal/hr of heat. Thus, by merging the duties of these two heat exchangers, the system actually is capable of transferring approximately 1.7 % more heat within the system. This is due to the fact that the reflux subcooler is typically of a less efficient cross-current design, and the main heat exchanger is typically of a more efficient counter-current design. This reduction, or elimination, of the reflux subcooler 13, and the associated piping will result in a substantially lower overall capital equipment cost.

[0079] After the distillation of the reflux liquids, a "nearly pure" nitrogen stream 20 is withdrawn from the top of the LP distillation column (23). This "nearly pure" nitrogen stream (20) typically has a composition of approximately 98.2 % nitrogen, 0.7 % oxygen, and 1.1 % argon (mole fraction), but may be of another composition considered to be nearly pure by one skilled in the art, for example at least 90 % mol. It also likely has a pressure of approximately 1.2 to 2 bar, a temperature of approximately -190 to -193°C. This stream 20 then passes through the main heat exchanger 6, where it is warmed due to the heat transfer to the inlet air stream. It is then exported as low-pressure gaseous nitrogen product 22. This low-pressure gaseous nitrogen product stream 22 has a pressure of approximately 1.0 to 1.5 bar, and a temperature of approximately 10 to 40°C.

[0080] The other main product of this second distillation process is a "nearly pure" oxygen stream 16 which is withdrawn at the base of the LP distillation column 23. This "nearly pure" oxygen stream 16 typically has a composition of approximately 95 % to 99.8 % oxygen, but may be of another composition considered to be nearly pure by one skilled in the art, such as at least 70 %. It also likely has a pressure of approximately 1.2 to 2 bar, a temperature of approximately -179°C, and if so desired, for either backup purposes or for sale as a product, this low-pressure liquid oxygen can be removed from the system at this point. In this embodiment, 0 to 30 % of the liquid oxygen that is leaving the LP distillation column 16, is removed as liquid oxygen product 26. Since the primary design goal of the classic pumping cycle is to produce relatively high-pressure gaseous oxygen, the pressure of this low-pressure liquid is increased significantly by means of a cryogenic pump 17. This high-pressure liquid oxygen stream 18 then passes through the main heat exchanger 6, where it is vaporized due to the heat transfer to the inlet air stream. It is then exported as high-pressure gaseous oxygen product 19. The high-pressure gaseous oxygen product stream 19 has pressure range of 20 to 80 bar, and a temperature of approximately 10 to 40°C.

[0081] Figure 7 is based on Figure 4 and differs therefrom in that the oxygen enriched liquid stream 11 is divided in two parts, in any desired proportions. Part 11 A is not cooled but the rest 11B is subcooled in subcooler 13 with air stream 10 by heat exchange with stream 20. The two streams 11A, 11B are then mixed, expanded in valve 27 to form stream 14 which enters the middle of the low pressure column 23 containing between 13 and 17% gas. The proportion of gas in stream 14 will be less than in the case of Figure 4 but the subcooler will be smaller. The subcooler 13 can form part of the heat exchanger 6. Stream 17 contains substantially 17% gas.

[0082] Figure 8 is based on Figure 5 and differs therefrom in that the nitrogen enriched liquid stream 12 is divided in two parts, in any desired proportions. Part 12 A is not cooled but the rest 12B is subcooled in subcooler 13 with air stream 10 by heat exchange with stream 20. The two streams 12A, 12B are then mixed, expanded in valve 28 to form stream 15 which enters the top of the low pressure column 23 containing between 13 and 17% gas. The proportion of gas in stream 15 will be less than in the case of Figure 5 but the subcooler will be smaller. The subcooler 13 can form part of the heat exchanger 6. Stream 14 contains substantially 17 % gas.

[0083] The partial cooling of Figures 7 and 8 may also be achieved by using a underdimensioned subcooler to cool all of the rich liquid 11 and/or the liquid air 10 and/or the pure liquid 12, the result being that the cooled reflux liquids are less cold than those of the prior art and consequently contain more flash gas following expansion.

[0084] In all the versions of Figures 7 and 8, the air stream which has served to vaporize a liquid stream and is then expanded in valve 31 enters column 23 containing at least 1,6 %, preferably at least 1,7 % and/or at most 15 %, preferably at most 5 % gas.

[0085] In Figures 4, 5, 7 and 8, an air separation plant incorporating a double distillation column, coupled with an argon distillation column, can be improved by way of this invention, by the partial or complete removal of the reflux subcooler (see US -A-6347534).

[0086] In Figures 4, 5, 7 and 8 an air separation plant incorporating three or more distillation columns, and utilizing a reflux subcooler, can be improved by way of this invention, by the partial or complete removal of the reflux subcooler (see US-A- 6347534).

[0087] This third distillation column can be an intermediate pressure column for the distillation of air or a gas derived from air such as the rich liquid.

[0088] In another alternative embodiment, an air separation plant incorporating three or more distillation columns,

coupled with an argon distillation column, can be improved by way of this invention, by the partial or complete removal of the reflux subcooler.

[0089] Preferably the reflux subcooler is completely removed from these systems.

[0090] Preferably these systems include at least one cryogenic pump for pumping liquid oxygen and/or nitrogen to be vaporized in the exchanger 6.

[0091] For a given product output, a classical gas cycle installation will typically have a total capital cost that is higher than classical pumping cycle. In turn, a classical pumping cycle installation will typically have a total capital equipment cost that is higher than an offset knee cycle.

[0092] For the classical gas cycle, there is typically a large oxygen compressor, and often a large nitrogen compressor as well. These typically operate at moderate to high pressure. For the classical pumping cycle configuration, there are a greater number of large pieces of rotating equipment, typically operating at higher pressure. The rotating equipment capital cost for a typical classical gas cycle installation will be higher than that of a classical pumping cycle plant of identical output. In turn, the rotating-equipment capital cost for a typical classical pumping cycle installation will be higher than that of an offset knee plant of identical output. In either type of plant, the capital cost of the rotating equipment is approximately one half of the total capital cost of the plant.

[0093] The reflux subcooler was previously considered to be essential for the proper functioning of the distillation columns.

[0094] The present invention takes the step of removing this reflux subcooler from or reducing this reflux subcooler in any air separation process in which pumped cryogenic liquid is vaporized by heat exchange with a calorogenic fluid. As discussed above, there is a fundamental difference between a classic gas plant and a pumping cycle plant, in that the liquid air that is leaving the main heat exchanger in a pumping cycle plant may even be sufficiently subcooled, from having exchanged its heat to superheat the high pressure liquid oxygen, as to provide adequate subcooling to the LP distillation column in the absence of any reflux subcooler. The removal of the reflux subcooler and all the associated interconnecting piping and instrumentation, has only a very small impact on the total oxygen recovery when applied to a pumping cycle, as shown in Figure 6.

[0095] One benefit this invention offers over the prior art is that it greatly simplifies either the classical pumping cycle or the offset knee cycle, by removing or reducing the reflux subcooler and all the associated interconnecting piping and instrumentation, thereby significantly reducing the total capital cost, as well as the total installed cost and overall maintenance cost. This invention can also be utilized to incorporate a syngas plant in the typical GTL or methanol plant in a remote location, by providing high-pressure oxygen in a less complicated plant which is more reliable, and hence less expensive to maintain.

[0096] In summary, in a project such as an integrated syngas and air separation plant, the air separation unit component is typically 15 % to 20 % of the total capital investment. In a typical air separation unit installation, such as an integrated syngas and air separation plant which enter very competitive markets, and have relatively small margins of profit, the use of this invention in a pumping cycle offers significant capital cost and maintenance cost advantages.

[0097] To illustrate the operation of the present invention, the table shows the percentage of vapor after the pressure reducing valves 27, 28, 31 for the three reflux streams 10, 14, 15.

Stream Description	Rich Liquid	Liquid Air	Pure Nitrogen Reflux
Stream Number	14	10	15
Prior Art (Fig. 3)	12.87 %	15.2 %	3.02 %
No Subcooler (Fig. 5)	17.06 %	1.53 %	17.35%
Partial Subcooling RL(Fig. 7)	12.87 - 17.06 %		
Partial subcooling air (not shown)		1.53 - 15.2 %	
Partial subcooling PNR (Fig. 8)			3.02 - 17.35 %

[0098] The air stream or the partial reflux streams may be subcooled against a single nitrogen enriched stream from the low pressure column, which may be the top stream as shown or an intermediate stream or against several nitrogen enriched streams from the low pressure column.

[0099] The air separation unit may produce nitrogen rich fluids of different purities from the low pressure column and in this case nitrogen enriched liquid having two different purities may be sent from the medium pressure column to the low pressure columns. One or both of these streams may be either not subcooled or only partially subcooled before being sent to the low pressure column.

Claims

1. Process for producing nitrogen and/ or oxygen by cryogenic distillation of air in an air separation unit comprising at least a medium pressure column (24) and a low pressure column (23) comprising the steps of

5 e) sending cooled compressed gaseous air to at least the medium pressure column
 f) removing an oxygen enriched liquid (11) and a nitrogen enriched liquid (12) from the medium pressure column
 g) expanding at least part of the nitrogen enriched liquid (12) to produce a nitrogen enriched fluid (15) and
 10 sending at least part of the expanded nitrogen enriched fluid into the low pressure column
 h) removing oxygen rich fluid (16) and nitrogen rich fluid (20) from the low pressure column

characterized in that wherein at least part of the expanded nitrogen enriched liquid is sent from the medium pressure column to the low pressure column without undergoing a cooling step prior to expansion.

- 15 2. Process according to Claim 1 wherein the nitrogen enriched fluid (15) sent into the low pressure column contains at least 3,5 % gas, preferably at least 4 % gas.

3. Process according to Claim 1 or 2 comprising the steps of expanding at least part of the oxygen enriched liquid (11) to form an expanded oxygen enriched fluid (14) and sending at least part of the expanded oxygen enriched fluid to the low pressure column wherein the oxygen enriched fluid (14) sent into the low pressure column (23) contains at least 13 %, preferably at least 13,5 % gas.

4. Process according to Claim 1, 2 or 3 wherein at least part of the expanded oxygen enriched liquid is sent to the low pressure column (23) without undergoing a cooling step prior to expansion.

5. Process according to any of Claims 1 to 4 wherein part (11B) of the oxygen enriched liquid to be expanded is cooled by heat exchange with nitrogen rich fluid (20) from the low pressure column (23) and part (11A) of the oxygen enriched liquid to be expanded is not cooled by heat exchange with nitrogen rich fluid from the low pressure column before being sent to the low pressure column and/or part of the nitrogen enriched liquid (12B) to be expanded is cooled by heat exchange with nitrogen rich fluid from the low pressure column and part (11A) of the nitrogen enriched liquid to be expanded is not cooled by heat exchange with nitrogen rich fluid (20) from the low pressure column (23) before being sent to the low pressure column.

6. Process according to Claim 1 to 5 wherein none of the oxygen enriched liquid (11) is cooled by heat exchange with nitrogen rich fluid (20) from the low pressure column (23) before being sent to the low pressure column (23) and /or none of the nitrogen enriched liquid (12) is cooled by heat exchange with nitrogen rich fluid (20) from the low pressure column (23) before being sent to the low pressure column

7. Process according to any preceding claim wherein a portion (7,8,) of the cooled compressed air is used to vaporize a liquid (18) removed from the low pressure column or the high pressure column, at least part (10) of the portion of the cold compressed air is sent to the low pressure column in liquid form following a subcooling step and an expansion step.

8. Process according to Claim 7 wherein at least 1,6 %, preferably at least 1,7 % and/or at most 15 %, preferably at most 5 % of the at least part of the portion of cold compressed air (10) sent to the low pressure column is in gaseous form.

9. Process according to Claim 7 or 8 wherein nitrogen enriched gas (20) is removed from the top of the low pressure column (23) and exchanges heat with the at least part (10) of the portion of the cooled compressed air during the subcooling step.

10. Process according to Claim 7, 8 or 9 wherein all of the feed air is compressed to a high pressure, a portion (7) of the air is used to vaporize a liquid (18) removed from the low pressure column or the high pressure column and the rest (4) of the air is expanded to the pressure of the medium pressure column in a turbine (5) and is sent to the medium pressure column (24) in at least partly gaseous form.

11. Process according to any of the preceding claims wherein at least one liquid (26) is withdrawn from a column (23) of the unit as a final product.

12. Installation for producing nitrogen and/or oxygen by cryogenic distillation of air in an air separation unit comprising at least a medium pressure column (24) and a low pressure column (23) comprising

- a) means for sending cooled compressed gaseous air to at least the medium pressure column
- b) means for removing an oxygen enriched liquid (11) from the medium pressure column and means for removing a nitrogen enriched liquid (12) from the medium pressure column
- c) expanding means (28) for expanding at least part of the nitrogen enriched liquid (12) to produce a nitrogen enriched fluid (15) and sending at least part of the expanded nitrogen enriched fluid into the low pressure column
- d) means for removing oxygen rich fluid (16) and nitrogen rich fluid (20) from the low pressure column

characterized in that there are no means for cooling at least part (12, 12A) of the nitrogen enriched liquid upstream of the nitrogen enriched liquid expanding means, preferably no means for cooling the nitrogen enriched liquid upstream of the nitrogen enriched liquid expanding means.

13. Installation according to Claim 12 comprising means for sending at least part of the oxygen enriched liquid (11) directly or indirectly to the low pressure column (23) and expanding means (27) for expanding the oxygen enriched liquid upstream of the low pressure column.

14. Installation according to Claim 13 wherein there are no means for cooling at least part of the oxygen enriched liquid (11,11A) upstream of the oxygen enriched liquid expanding means, preferably no means for cooling the oxygen enriched liquid upstream of the oxygen enriched liquid expanding means.

15. Installation according to one of Claims 12 to 14 comprising means for removing a liquid stream (16) from a column of the air separation unit and means (6) for vaporizing at least part of the liquid stream, preferably upstream of a pressurization means (17).

16. Installation according to Claim 15 comprising means (6) for vaporizing at least part of the liquid stream by heat exchange with an air stream, means (6,13) for subcooling at least part of the air stream by heat exchange with a nitrogen enriched stream (20) from the low pressure column (23), means (31) for expanding the subcooled air stream and means for sending the expanded subcooled air stream to the low pressure column.

17. Installation according to Claim 16 comprising a main heat exchanger (6), means for sending all the feed air (1) for the air separation unit and at least part of the liquid stream (16) to be vaporised to the main heat exchanger, means for sending the air stream to be subcooled (10) to the main heat exchanger and means for removing the subcooled air stream from the main heat exchanger upstream of the means (31) for expanding the subcooled air stream.

18. Installation according to Claim 16 comprising a subcooler (13) and means for sending only the air stream (10) and at least one nitrogen stream (20) from the low pressure column (23) to the subcooler.

19. Installation according to Claim 16,17 or 18 comprising means for compressing all the feed air to a high pressure, means (5) for expanding part of the air to the pressure of the medium pressure column (24), means for sending the expanded air to the medium pressure column, means for sending the rest (9,10) of the air to the low pressure column and possibly the medium pressure column following expansion and liquefaction.

20. Installation according to any of Claims 12 to 19 wherein the unit comprises an intermediate pressure column, means for feeding the intermediate pressure column with oxygen enriched liquid from the medium pressure column and means for feeding fluids from the intermediate pressure column to the low pressure column.

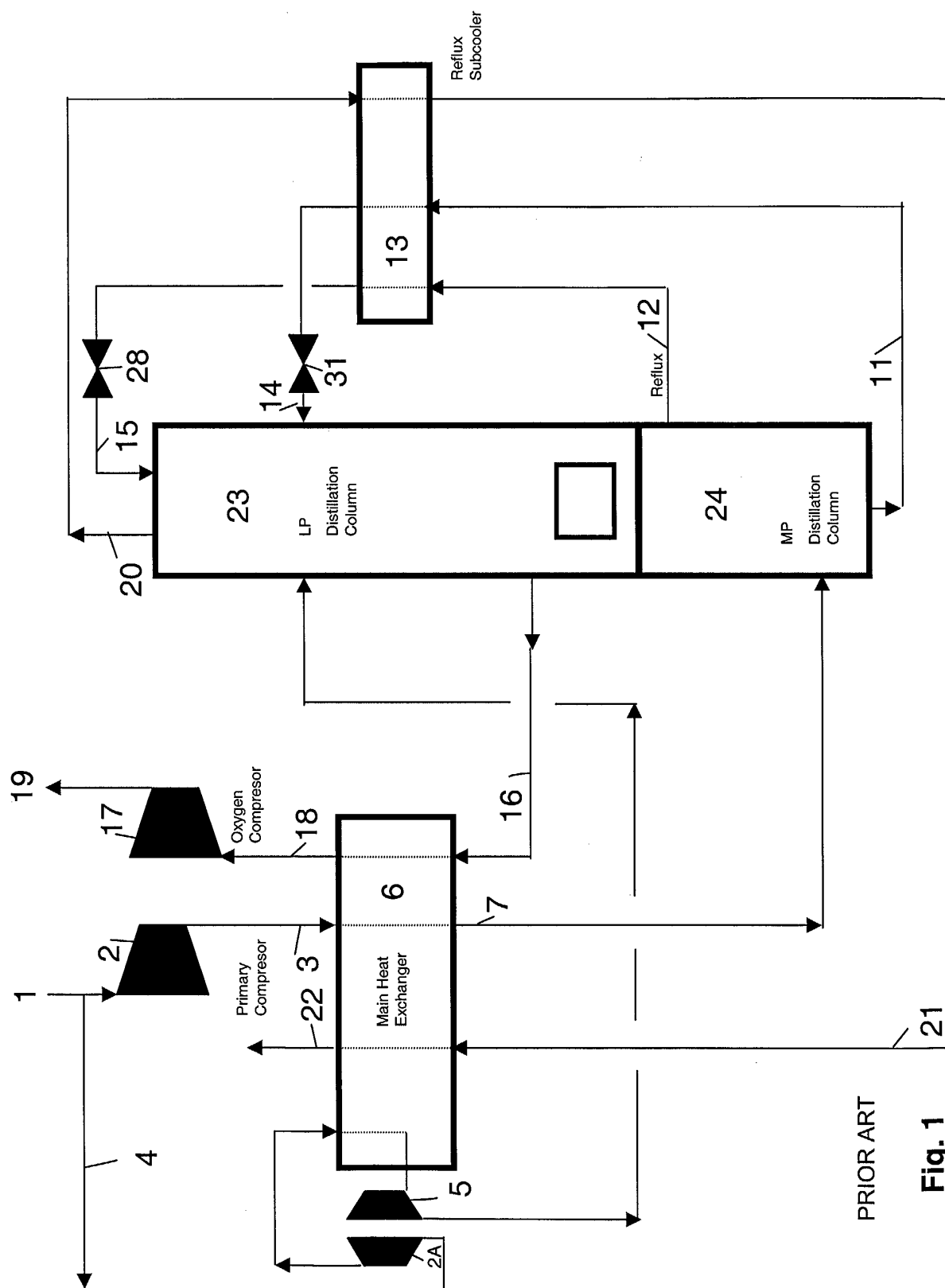
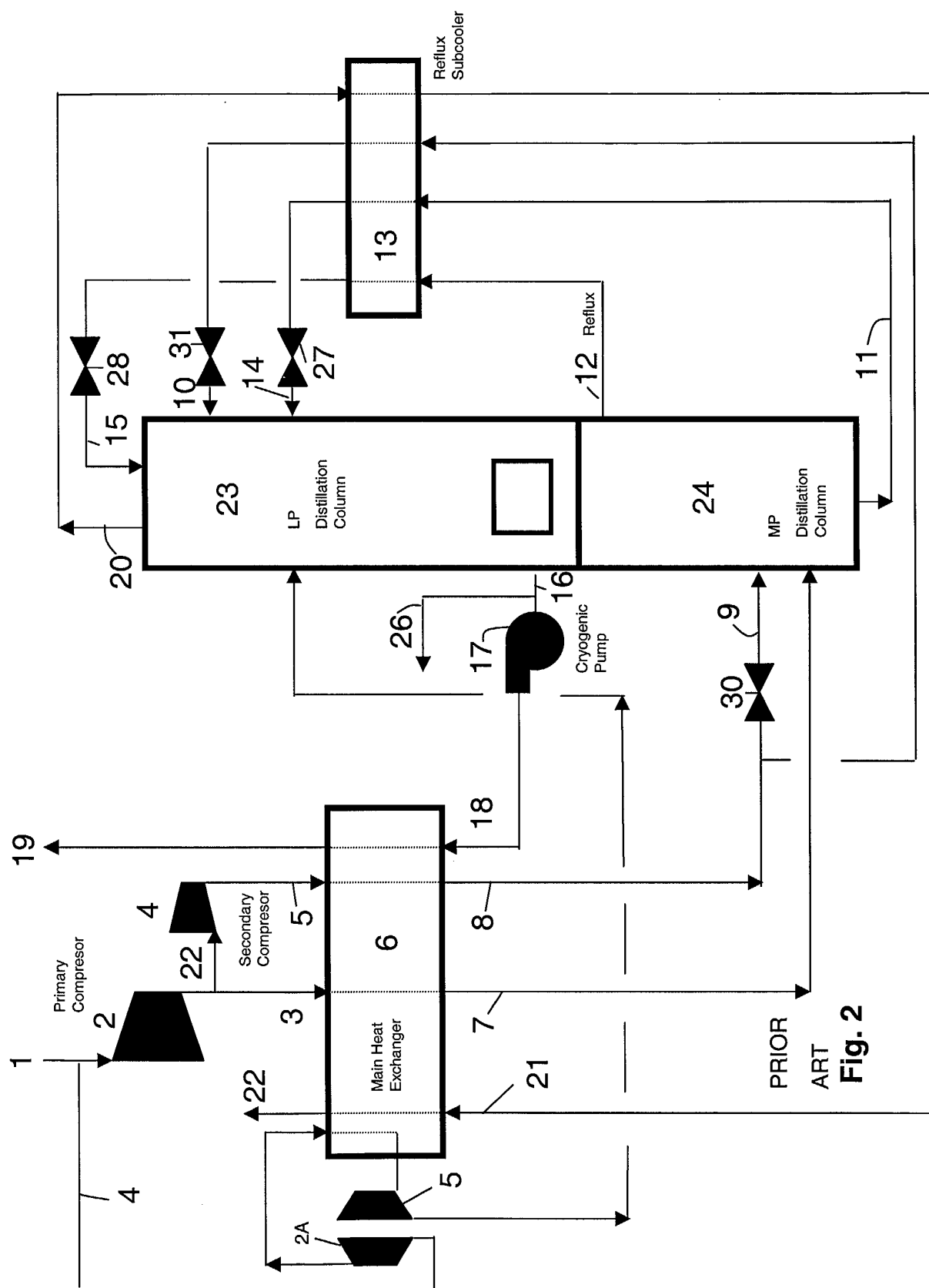
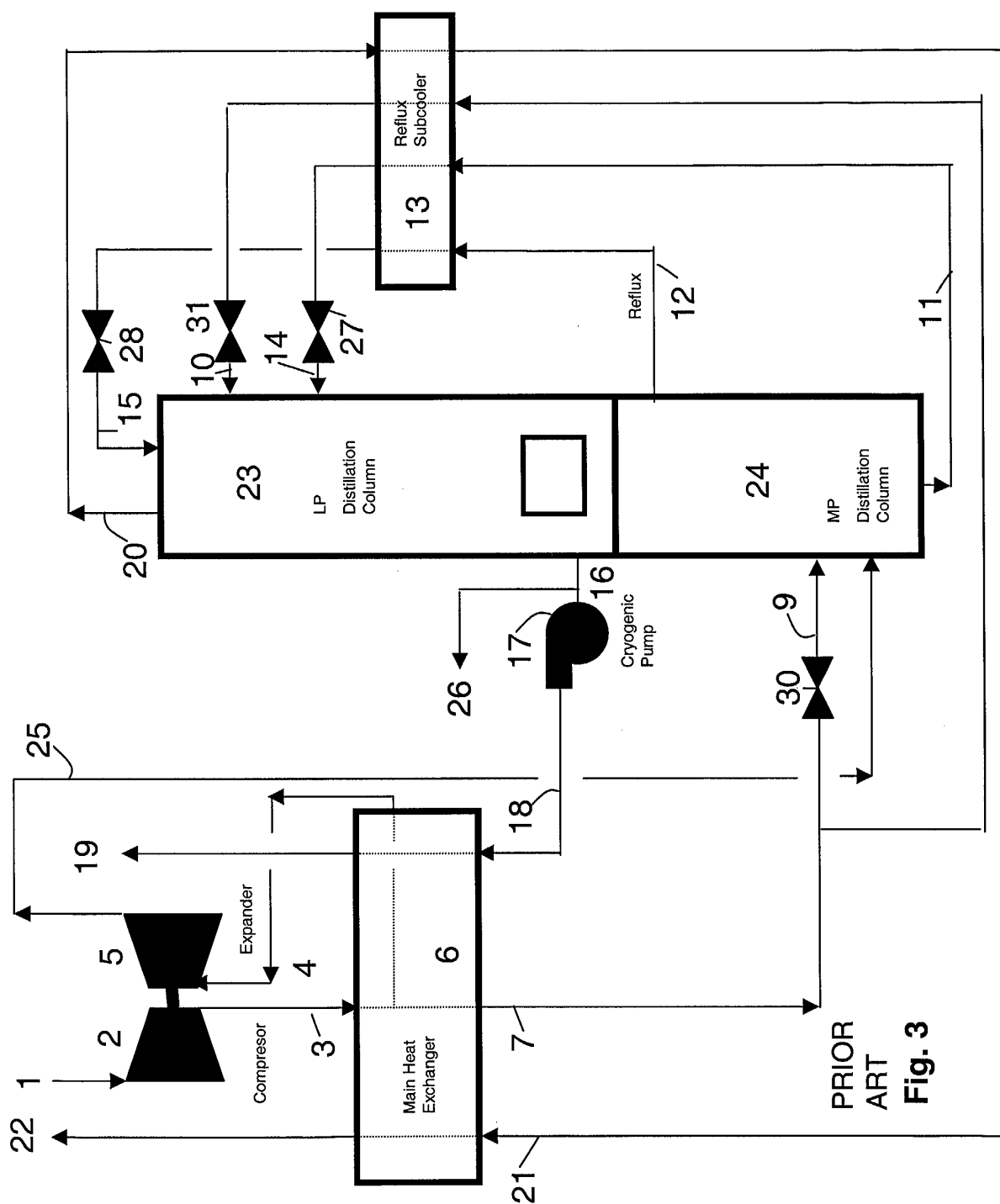


Fig. 1





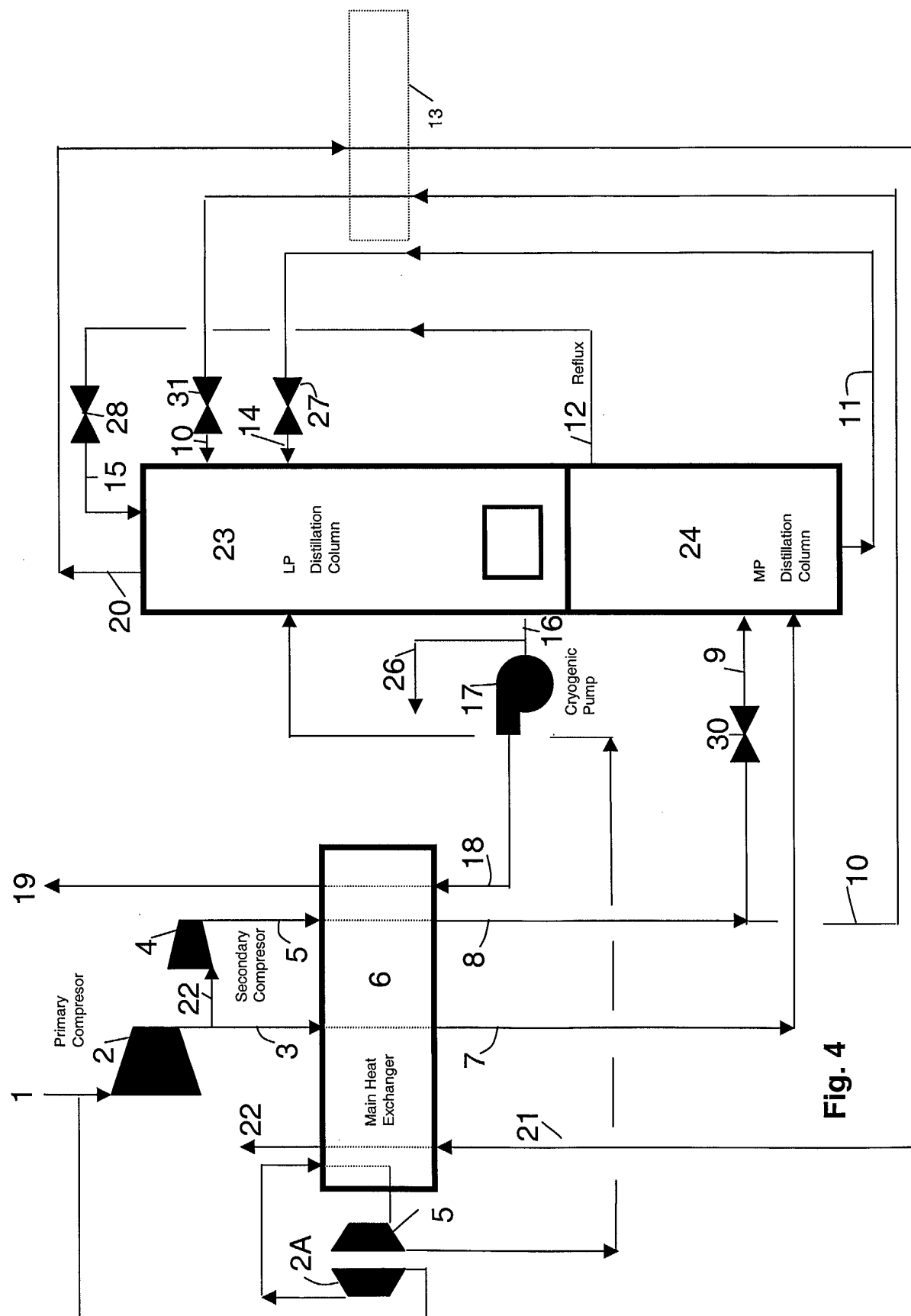
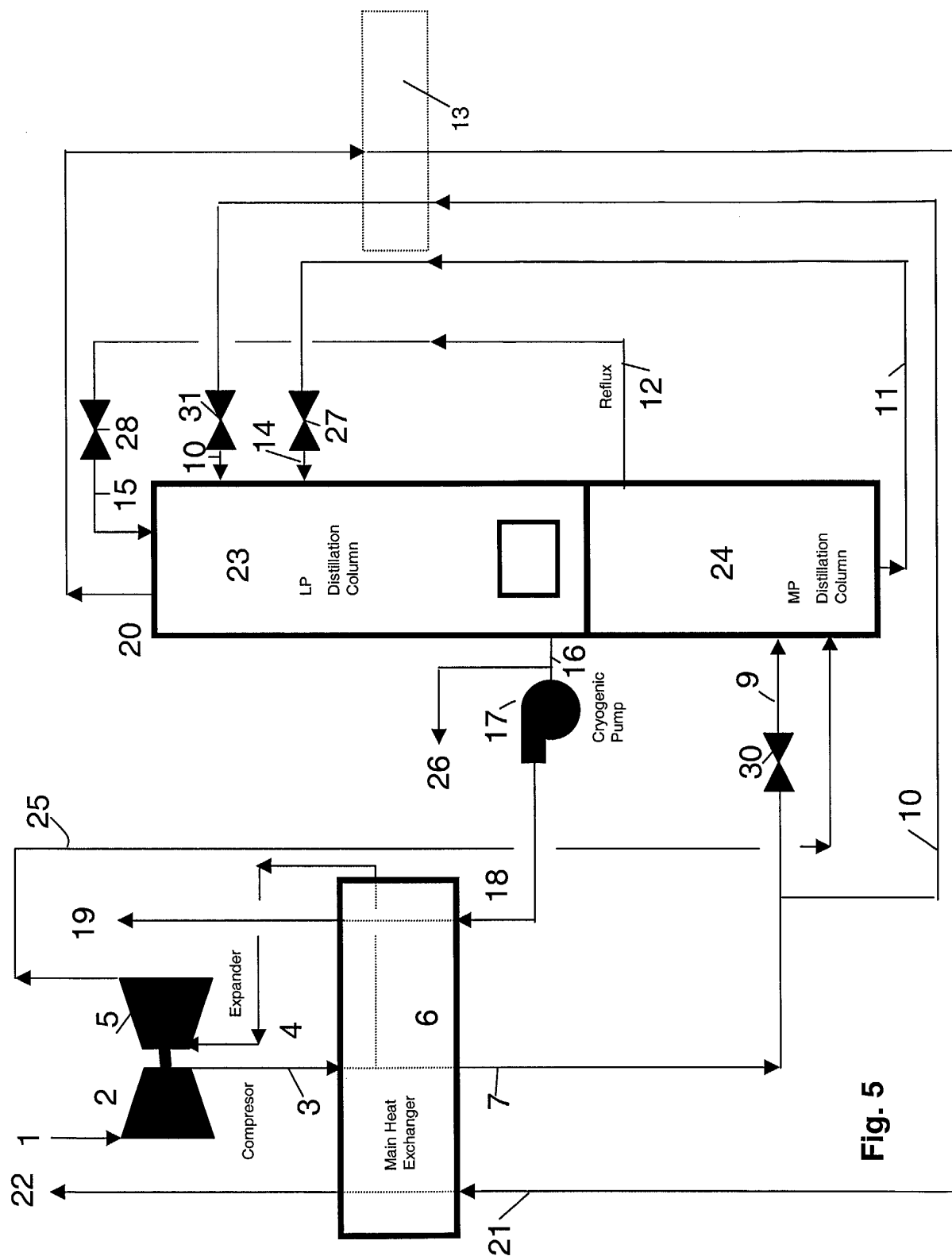


Fig. 4



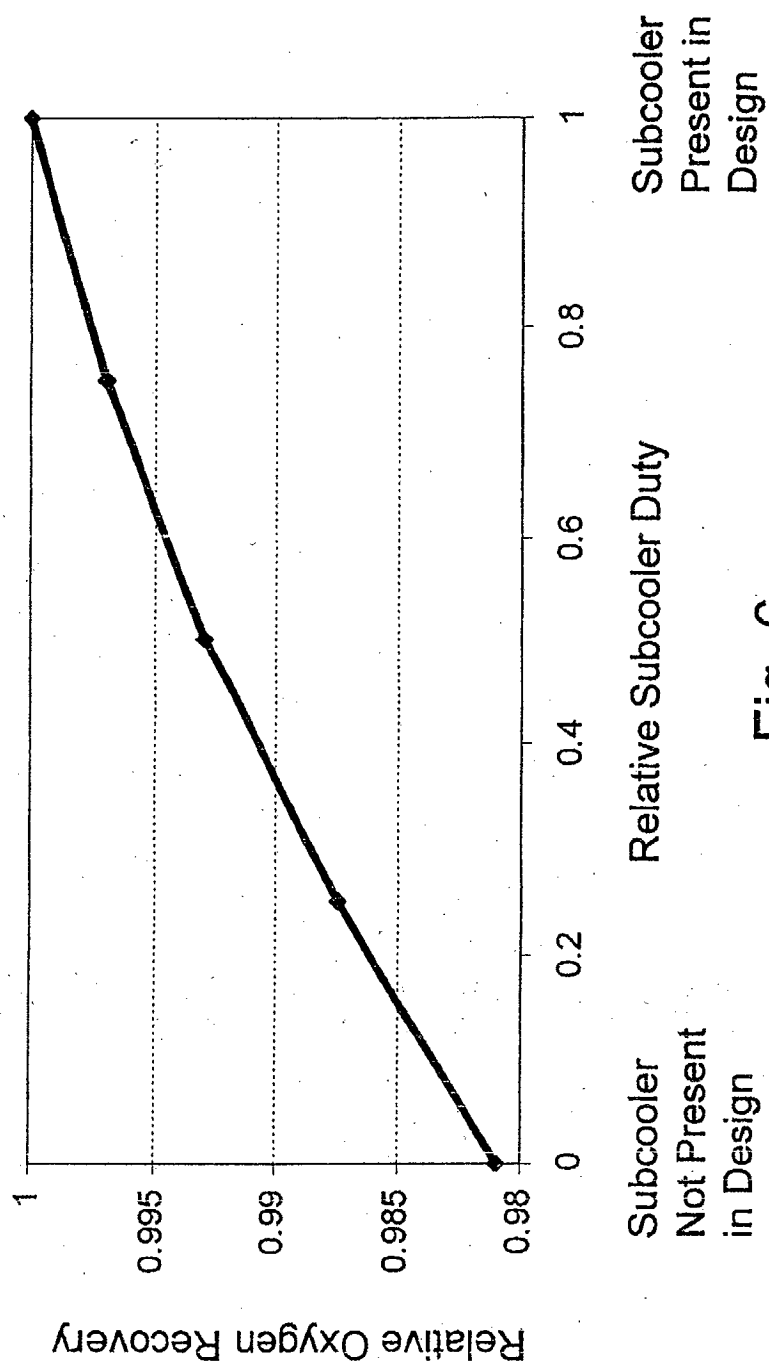


Fig. 6

