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(54) Title: AIR SEPARATION METHOD AND APPARATUS

(57) Abstract: A method and apparatus for separating air in which the recovery rate of an oxygen product is increased by increasing the liquid to vapor ratio in a lower pressure column connected to a higher pressure column in a heat transfer relationship. A crude liquid oxygen column bottoms stream produced in the higher pressure column is partially vaporized against condensing argon-enriched vapor of the lower pressure column which is fed back to an argon stripping section of the lower pressure column. A supplemental nitrogen-rich reflux stream and an oxygen-enriched stream having a greater oxygen content than the crude liquid oxygen stream are fed into the lower pressure column. These streams are formed from a two phase stream produced, at least in part, from the crude liquid oxygen stream after the partial vaporization thereof.



AIR SEPARATION METHOD AND APPARATUS

Field of the Invention

[0001] The present invention relates to a method and apparatus for separating air to produce an oxygen product in which the air is separated by cryogenic rectification in higher and lower pressure columns operatively associated with one another in a heat transfer relationship to produce an oxygen product from an oxygen-rich liquid column bottoms produced in the lower pressure column. More particularly, the present invention relates to such a method and apparatus in which a crude liquid oxygen stream removed from the higher pressure column is used to condense argon-enriched vapor within the lower pressure column and to generate a supplemental liquid nitrogen-rich reflux stream and an oxygen-enriched stream that are introduced into the lower pressure column for purposes of increasing oxygen recovery.

Background of the Invention

[0002] Oxygen is separated from air through cryogenic rectification within an air separation plant. In such a plant the air is compressed and purified and then cooled within a main heat exchanger to a temperature suitable for its rectification. The cooled air is then introduced into a system of distillation columns having a higher pressure column operatively associated with a lower pressure column by means of a condenser reboiler that partly vaporizes an oxygen-rich liquid column bottoms of the lower pressure column against condensing a nitrogen-rich vapor produced as column overhead of the higher pressure column. The resulting nitrogen-rich liquid is used to form reflux for both of the columns. Additionally, a crude liquid oxygen stream composed of a column bottoms of the higher pressure column is further refined in the lower pressure column to further separate the oxygen from the nitrogen and thereby produce an oxygen-rich liquid column bottoms in the lower pressure column. At least a portion of the oxygen product is formed from the oxygen-rich liquid column bottoms and can be pumped to produce a pressurized oxygen product.

[0003] In order to separate the oxygen so that most of the oxygen is separated from the air, there must be a sufficient liquid to vapor ratio within the uppermost sections of the lower

pressure column in order to enrich the ascending vapor in nitrogen. Similarly there must exist sufficient low pressure column reboil in order to effectively strip argon and nitrogen from the descending liquid. Where the product oxygen is pumped, roughly 30 to 40 percent of the air is liquefied to provide the energy necessary to warm the pressurized liquid oxygen within the main heat exchanger. The liquid air is then fed into the columns for rectification. In many instances, the liquid air and nitrogen rich liquid flows are insufficient to reflux lower pressure column in order to maintain high oxygen recovery. It is to be noted, that the liquid to vapor ratio suffers in both the lower and higher pressure columns when condensed liquid or gaseous nitrogen is extracted as product from the higher pressure column.

[0004] As will be discussed, the present invention provides a method and apparatus for separating the air in which the liquid to vapor ratio is increased within the rectifications sections of lower pressure column over prior art methods to increase the recovery of the oxygen from the air.

Summary of the Invention

[0005] In one aspect, the present invention provides a method of separating air to produce an oxygen product. In accordance with such method, the air is separated in a cryogenic rectification process having a higher pressure column and a lower pressure column operatively associated with one another in a heat transfer relationship to produce nitrogen-rich reflux for the higher pressure column and the lower pressure column. The oxygen product is produced from an oxygen-rich liquid column bottoms of the lower pressure column.

[0006] The cryogenic rectification process is conducted such that a crude liquid oxygen stream formed of a crude liquid oxygen column bottoms produced in the higher pressure column is partially vaporized against at least partially condensing an argon-enriched vapor produced in the lower pressure column. A supplemental nitrogen-rich reflux stream and an oxygen-enriched stream having a greater oxygen content than the crude liquid oxygen stream are both formed from a two-phase stream produced, at least in part, from the crude liquid oxygen stream after partial vaporization thereof. The oxygen-enriched stream and at least part of the supplemental nitrogen-rich reflux stream are fed into the lower pressure

column. The argon-enriched vapor is at least partially condensed at a location of the lower pressure column where the argon-enriched vapor has an nitrogen concentration of between 0.1 mole percent and 5.0 mole percent. The resulting condensate will combine with downcoming liquid of the lower pressure column to increase a liquid to vapor ratio in a lowermost section of the lower pressure column. The oxygen-enriched stream and the at least part of the supplemental nitrogen-rich liquid stream are fed at successively higher locations of the lower pressure column and above the location of the lower pressure column at which the argon-enriched vapor is at least partially condensed.

[0007] As can be appreciated, the intermediate condensation of the argon and the formation of the supplementary liquid nitrogen reflux stream increases the liquid to vapor ratio within the lowermost sections of the lower pressure column. Additionally, since the oxygen containing stream is richer in oxygen than the crude liquid oxygen stream, and additional lower pressure reflux has been generated, oxygen recovery will be increased.

[0008] Although the present invention has general applicability to air separation plants employing higher and lower pressure columns, it is particularly applicable to pumped liquid oxygen plants due to the fact that a meaningful portion of the feed air is condensed prior to entry into the columns and is particularly useful in the production of oxygen having a purity of 99.5 percent and greater. Such plants have a lower base level recovery relative to plants in which the oxygen product is primarily gaseous oxygen recovered from the lower pressure column. In this regard, the oxygen product can be produced from an oxygen-rich liquid column bottoms of the lower pressure column by pumping at least part of an oxygen-rich column bottoms stream withdrawn from the lower pressure column and composed of the oxygen-rich liquid column bottoms to form a pressurized liquid oxygen stream. At least part of the pressurized liquid oxygen stream is warmed through indirect exchange with a high pressure process stream such that it is liquefied. In this regard, in any embodiment of the present invention, such a high pressure process stream could be a high pressure air stream that is liquefied to form a liquid air stream. The oxygen product is formed from the at least part of the pressurized oxygen stream after having been warmed and at least part of the high pressure stream, after liquefaction, is introduced into at least one of the higher pressure column and the lower pressure column.

[0009] In a specific embodiment, the crude liquid oxygen stream is valve expanded and partially vaporized and then is passed in indirect heat exchange with the argon-enriched rich vapor. The supplemental nitrogen-rich reflux stream and the oxygen-enriched stream are formed by disengaging liquid and vapor phases from the two-phase stream to form a vapor phase stream and a liquid phase stream. The liquid phase stream is valve expanded and then partially vaporized in indirect heat exchange with the vapor phase stream thereby condensing the vapor phase stream to form the supplemental nitrogen-rich reflux stream and the oxygen-enriched stream from the liquid phase stream after the liquid phase stream has been partially vaporized. The at least part of the nitrogen-rich reflux stream is valve expanded and introduced into the lower pressure column and the oxygen-enriched stream is introduced into the lower pressure column.

[0010] In another specific embodiment, the high pressure process stream is formed from a high pressure air stream that after liquefaction forms a liquid air stream and at least part of the liquid air stream is divided into a first subsidiary liquid air stream and a second subsidiary liquid air stream. The first subsidiary liquid air stream is valve expanded and introduced into the lower pressure column. The supplemental nitrogen-rich reflux stream and the oxygen-enriched stream are formed by disengaging liquid and vapor phases from the two-phase stream to form a vapor phase stream and a liquid phase stream. The vapor phase stream is introduced into a bottom region of an auxiliary column and the second subsidiary liquid air stream is introduced into an intermediate location of the auxiliary column to form an oxygen containing bottoms liquid and a supplemental nitrogen-rich vapor column overhead within the auxiliary column. A combined oxygen-enriched stream is formed by combining the liquid phase stream with an oxygen containing bottoms liquid stream formed of the oxygen containing bottoms liquid. A supplemental nitrogen-rich vapor column over head stream formed of the supplemental nitrogen-rich vapor column overhead is condensed through indirect heat exchange with the combined liquid stream after the valve expansion thereof. This results in partial vaporization of the combined liquid stream and forms the oxygen-enriched stream and the supplementary nitrogen-rich reflux stream and also, an auxiliary column reflux stream. The auxiliary column is refluxed with the auxiliary column reflux stream and the at least part of the subsidiary

nitrogen-rich liquid stream is valve expanded and introduced into the lower pressure column.

[0011] In either of such embodiments, the liquid nitrogen reflux to the higher pressure column and the lower pressure column is produced by condensing a higher pressure nitrogen-rich vapor stream composed of higher pressure nitrogen-rich vapor produced in the higher pressure column through indirect heat exchange with the oxygen-rich liquid column bottoms of the lower pressure column, thereby to produce a condensed nitrogen-rich stream. The higher pressure column is refluxed with at least part of the condensed nitrogen-rich stream. An impure nitrogen-rich liquid stream can be removed from the higher pressure column, subcooled and valve expanded and then used to reflux the lower pressure column.

[0012] A lower pressure nitrogen-rich vapor stream composed of a lower pressure nitrogen-rich vapor produced in the lower pressure column can be removed from the lower pressure column. The lower pressure nitrogen-rich vapor stream passes in indirect heat exchange with the crude liquid oxygen stream and the impure nitrogen-rich liquid stream to subcool the crude liquid oxygen stream and the impure nitrogen-rich liquid stream. The lower pressure nitrogen-rich vapor stream is passed in indirect heat exchange with a compressed and purified air stream composed of the air to be separated. The compressed and purified air stream after having been cooled is introduced into a bottom region of the higher pressure column.

[0013] As mentioned above, in any embodiment of the present invention, the high pressure process stream can be a high pressure air stream that is liquefied to form a liquid air stream. In such case, after the high pressure air stream has been partially cooled, the high pressure air stream can be divided into a first subsidiary high pressure air stream and a second subsidiary high pressure air stream. The first subsidiary high pressure air stream is fully cooled and forms the liquid air stream. The second subsidiary high pressure air stream, after having been partially cooled, is expanded in a turboexpander and introduced into the bottom region of the higher pressure column to impart refrigeration into the cryogenic rectification process. The higher pressure column can be refluxed with a first part of the condensed nitrogen-rich stream. A second part of the condensed nitrogen-rich stream can be passed in indirect heat exchange with the lower pressure nitrogen-rich vapor

stream along with the impure nitrogen-rich liquid stream and the crude liquid oxygen stream to form a liquid nitrogen product stream. A third part of the condensed nitrogen-rich stream can be pumped and warmed through indirect heat exchange with the high pressure air stream along with the oxygen-rich column bottoms stream to form a pressurized nitrogen product stream.

[0014] The present invention in another aspect provides an apparatus for separating air to produce an oxygen product. In accordance with this aspect of the present invention, an air separation plant is configured to separate the air through cryogenic rectification. The plant has a higher pressure column and a lower pressure column operatively associated with one another in a heat transfer relationship to produce nitrogen-rich reflux for the higher pressure column and the lower pressure column. A means is also included for producing the oxygen product from an oxygen-rich liquid column bottoms of the lower pressure column.

[0015] The operative association of the lower pressure column and the higher pressure column includes a means for partially vaporizing a crude liquid oxygen stream composed of a crude liquid oxygen column bottoms of the higher pressure column against at least partially condensing an argon-enriched vapor produced in the lower pressure column. Also included is a means for producing a supplemental nitrogen-rich reflux stream and an oxygen-enriched stream having a greater oxygen content than the crude liquid oxygen column bottoms from a two-phase stream. The two-phase stream is produced, at least in part, from the crude liquid oxygen stream after the partial vaporization thereof. The argon-enriched vapor is at least partially condensed at a location of the lower pressure column where the argon-enriched vapor has a nitrogen concentration of between 0.1 mole percent and 5.0 mole percent. The resulting condensate will combine with downcoming liquid of the lower pressure column and increase the liquid to vapor ratio in a lowermost section of the lower pressure column. The supplemental nitrogen-rich reflux stream and the oxygen-enriched stream producing means is connected to the lower pressure column such that the oxygen-enriched stream and at least part of the supplemental nitrogen-rich liquid stream is fed at successively higher locations of the lower pressure column and above the location of the lower pressure column at which the argon-enriched vapor is at least partially condensed.

[0016] The oxygen product producing means can comprise a pump connected to the lower pressure column such that at least part of an oxygen-rich column bottoms stream withdrawn from the lower pressure column and composed of the oxygen-rich liquid column bottoms is pumped by the pump to produce a pressurized liquid oxygen stream. A main heat exchanger is in flow communication with the pump and configured to warm at least part of the pressurized liquid oxygen stream through indirect exchange with a high pressure stream such that the at least part of the high pressure stream is liquefied and the oxygen product is formed from the at least part of the pressurized liquid oxygen stream after having been warmed. At least the lower pressure column is in flow communication with the main heat exchanger such that at least part of the high pressure process stream after having been liquefied is introduced into at least one of the higher pressure column and the lower pressure column.

[0017] In a specific embodiment of the present invention, the means for partially vaporizing the crude liquid oxygen stream comprises an intermediate heat exchanger in flow communication with the lower pressure column and configured to pass the crude liquid oxygen stream in indirect heat exchange with the argon vapor. The supplemental nitrogen-rich reflux stream and the oxygen-enriched stream producing means comprises a phase separator connected to the intermediate heat exchanger to disengage liquid and vapor phases from the two-phase stream and thereby to form a vapor phase stream and a liquid phase stream and an auxiliary heat exchanger connected to the phase separator and configured to partially vaporize the liquid phase stream in indirect heat exchange with the vapor phase stream. The auxiliary heat exchanger condenses the vapor phase stream and forms the supplemental nitrogen-rich reflux stream from the vapor phase stream after condensation thereof and the oxygen-enriched stream from the liquid phase stream after partial vaporization of the liquid phase stream. The auxiliary heat exchanger is connected to the lower pressure column such that the oxygen-enriched stream and the at least part of the supplemental nitrogen-rich reflux stream are introduced into the lower pressure column. An arrangement of expansion valves are positioned for expanding: the crude liquid oxygen stream before being partially vaporized; the liquid phase stream prior to the indirect heat exchange with the vapor phase stream; and the at least part of the nitrogen-rich reflux stream before being introduced into the lower pressure column.

[0018] In another embodiment, that also uses the intermediate heat exchanger, the high pressure process stream is a high pressure air stream that after liquefaction thereof forms a liquid air stream. The lower pressure column is in flow communication with the main heat exchanger such that at least part of the liquid air stream is divided into a first subsidiary liquid air stream that is introduced into the lower pressure column and a second subsidiary liquid air stream. The supplemental nitrogen-rich reflux stream and the oxygen-enriched stream producing means comprises a phase separator connected to the intermediate heat exchanger in the manner described above. An auxiliary column is connected to the phase separator and the main heat exchanger such that the vapor phase stream is introduced into a bottom region of the auxiliary column and the second subsidiary liquid air stream formed from the liquid air stream is introduced into an intermediate location of the auxiliary column. An oxygen containing bottoms liquid and a supplemental nitrogen-rich vapor column overhead are formed within the auxiliary column. An auxiliary column heat exchanger is connected to the auxiliary column and the phase separator such that the liquid phase stream is combined with an oxygen containing bottoms liquid stream formed of the oxygen containing bottoms liquid and the combined liquid stream passed in indirect heat exchange with a supplemental nitrogen-rich vapor column over head stream formed of the supplemental nitrogen-rich vapor column overhead. The auxiliary column heat exchanger condenses the supplemental nitrogen-rich vapor stream and partially vaporizes the combined liquid stream to form the oxygen-rich reflux stream, the supplementary nitrogen-rich reflux stream and also, an auxiliary column reflux stream. An arrangement of expansion valves is positioned for expanding: the crude liquid oxygen stream before being partially vaporized; the first subsidiary liquid air stream prior to being introduced into the lower pressure column; the combined liquid stream prior to passing into the auxiliary column heat exchanger; and the at least part of the subsidiary nitrogen-rich liquid stream prior to introduction into the lower pressure column.

[0019] In either embodiment, a condenser reboiler can be connected to the higher pressure column and the lower pressure column such that a higher pressure nitrogen-rich vapor stream composed of high pressure nitrogen-rich vapor produced in the higher pressure column is condensed through indirect heat exchange with the oxygen-rich liquid column bottoms of the lower pressure column. The condensation produces a condensed nitrogen-

rich stream. The higher pressure column is connected to the condenser reboiler such that the higher pressure column is refluxed with at least part of the condensed nitrogen-rich stream. The lower pressure column is connected to the higher pressure column such that an impure nitrogen-rich liquid stream is removed from the higher pressure column and introduced into the lower pressure column. The subcooling unit is positioned between the higher pressure column and the lower pressure column such that the impure nitrogen-rich liquid stream is subcooled prior to being introduced into the lower pressure column. The arrangement of expansion valves also includes an expansion valve positioned between the subcooling unit and the lower pressure column such that the impure nitrogen-rich liquid stream is subcooled prior to being introduced into the lower pressure column.

[0020] The subcooling unit is connected to the lower pressure column and the higher pressure column and configured such that a lower pressure nitrogen-rich vapor stream composed of a lower pressure nitrogen-rich vapor produced in the lower pressure column passes in indirect heat exchange with the crude liquid oxygen stream and the impure nitrogen-rich liquid stream to subcool the crude liquid oxygen stream and the impure nitrogen-rich liquid stream. The main heat exchanger is connected to the subcooling unit such that the lower pressure nitrogen-rich vapor stream, after having passed through the subcooling unit, is passed in indirect heat exchange with a compressed and purified air stream composed of the air to be separated. The main heat exchanger is connected to the higher pressure column such that a compressed and purified air stream after having been cooled in the main heat exchanger is introduced into a bottom region of the higher pressure column.

[0021] The main heat exchanger can be configured such that after the high pressure air stream has been partially cooled, the high pressure air stream is divided into a first subsidiary high pressure air stream that is fully cooled and forms the liquid air stream and a second subsidiary high pressure air stream that is partially cooled prior to discharge from the main heat exchanger. A turboexpander is positioned between the main heat exchanger and the higher pressure column such that the second subsidiary high pressure air stream is expanded in a turboexpander and introduced into the bottom region of the higher pressure column to impart refrigeration into the air separation plant.

[0022] The higher pressure column can be connected to the condenser reboiler such that the higher pressure column is refluxed with a first part of the condensed nitrogen-rich stream. The subcooling unit is connected to the condenser reboiler such that a second part of the condensed nitrogen-rich stream is passed in indirect heat exchange with the lower pressure nitrogen-rich vapor stream along with the impure nitrogen-rich liquid stream and the crude liquid oxygen stream to form a liquid nitrogen product stream. Another pump can be positioned between the main heat exchanger and the condenser reboiler such that a third part of the condensed nitrogen-rich stream is pumped and then warmed in the main heat exchanger through indirect heat exchange with the high pressure air stream along with the oxygen-rich column bottoms stream to form a pressurized nitrogen product stream.

Brief Description of the Drawings

[0023] While the specification concludes with claims distinctly pointing out the subject matter that applicant regards as his invention, it is believed that the present invention will be better understood when taken in connection with the accompanying drawings in which:

[0024] Fig. 1 is a schematic illustration of an air separation plant designed to carry out a method in accordance with the present invention; and

[0025] Fig. 2 is a schematic illustration of an alternative embodiment of an air separation plant designed to carry out a method in accordance with the present invention.

Detailed Description

[0026] With reference to Figure 1, an air separation plant 1 is illustrated for separating a compressed and purified air stream 10 by cryogenic rectification to produce an oxygen product stream 64 and also, nitrogen products, such as a pressurized nitrogen product stream 96 and a liquid nitrogen product stream 92.

[0027] Air separation plant 1 may be included in an enclave of plants and therefore, the equipment that would be used to produce compressed and purified air stream 10 may be commonly used for all plants in the enclave. However, such equipment could be used solely for air separation plant 1 and would include a main air compressor and a pre-purification unit. Such a pre-purification unit, as known in the art, is designed to remove

higher boiling impurities from the air such as water vapor, carbon dioxide and hydrocarbons and can incorporate adsorbent beds operating in an out of phase cycle that is a temperature swing adsorption cycle or a pressure swing adsorption cycle or combinations thereof. After having been compressed and purified, the air can be further compressed in a booster compressor to produce a high pressure air stream 62 that will be discussed. Both the main air compressor and booster compressor can be multi-stage, intercooled integral gear compressors. The main air compressor may also incorporate condensate removal between stages.

[0028] The compressed and purified air stream 10 is then cooled to a temperature suitable for its rectification within a main heat exchanger 12 which is a temperature near saturation. Main heat exchanger 12, can be of brazed aluminum fin construction and, although not illustrated, can be a series of such heat exchangers operated in parallel. Furthermore, the main heat exchanger could be separated into a high pressure section for purposes of indirect heat exchange between the high pressure air stream 62, the oxygen product stream 64 and the pressurized nitrogen product stream 96. This being said the present invention may be employed independent of the selection and configuration of the main heat exchanger.

[0029] After having been cooled, the compressed and purified air stream 10 is introduced into a distillation column arrangement having a higher pressure column 14 and a lower pressure column 16. Higher pressure column 14 will have a higher operational pressure than lower pressure column 16 and will typically operate at a pressure of between 75 and 95 psia. The introduction of compressed and purified air stream 10 initiates the formation of an ascending vapor phase that becomes ever more rich in nitrogen as it ascends higher pressure column 14 and through mass transfer contacting elements 18, 20 and 22 that can be trays or structured packing or a combination of trays or structure packing or possibly random packing. As a result, a higher pressure nitrogen-rich vapor column overhead is produced within the higher pressure column 14 that is condensed to initiate the formation of a descending liquid phase that contacts the ascending vapor phase passing through mass transfer contacting elements 18, 20 and 22 to become ever more rich in oxygen and thereby to produce a crude liquid oxygen column bottoms 24, also known in the art as kettle liquid. In a manner that will be discussed, the crude liquid oxygen column bottoms

24 is removed as a crude liquid oxygen stream 26 that is further refined in the lower pressure column 16 in accordance with the present invention.

[0030] Lower pressure column 16 has mass transfer contacting elements 28, 30, 32 and 36 that function to contact an ascending vapor phase with a descending liquid phase and can be trays, structured packing or random packing or combinations thereof. As a result, an oxygen-rich liquid column bottoms 38 is produced along with a lower pressure nitrogen-rich vapor column overhead 56.

[0031] The lower pressure column 16 is linked to the higher pressure distillation column 14 in a heat transfer relationship by means of a condenser reboiler 40. Condenser reboiler 40 serves to condense a higher pressure nitrogen-rich vapor stream 42 composed of the higher pressure nitrogen-rich vapor column overhead of the higher pressure column 14. A portion of the oxygen-rich liquid column bottoms 38 is vaporized in condenser reboiler 40 to produce boilup in the lower pressure distillation column 16 and a condensed nitrogen-rich stream 43. The oxygen-rich liquid column bottoms 38 is thus, residual liquid that is not vaporized. Condenser reboiler 40 can be a conventional thermo-siphon type heat exchanger or a falling film, down-flow type heat exchanger.

[0032] The condensed nitrogen-rich stream 43 can be divided into a first part of the condensed nitrogen-rich stream 44, a second part of the condensed nitrogen-rich stream 46 and a third part of the condensed nitrogen-rich stream 48. The first part of the condensed nitrogen-rich stream 44 is used to reflux the higher pressure column 14. As would be known to those skilled in the art, all of the condensed nitrogen-rich stream 43 could be used for such purposes. Reflux for the lower pressure column 16 is generated from an impure nitrogen-rich liquid stream 50 removed from the higher pressure column 14. The impure nitrogen-rich liquid stream 50 is subcooled within a subcooling unit 52, valve expanded within an expansion valve 54 to a pressure compatible with the operating pressure of the lower pressure column 16 and then introduced into the lower pressure column 16 as reflux. The impure nitrogen-rich liquid stream 50 is typically withdrawn from a location in between the top of the higher pressure column 14 and a point at which liquid air 84 is fed into the higher pressure column 14; and will have a purity ranging typically from between 1000 and 20000 parts per million by volume oxygen. As would be known to those skilled in the art, reflux could also be generated for the lower pressure

column 16 through the use of part of the condensed nitrogen-rich stream 43. In such case, lower pressure column 16 would be designed to produce a lower pressure nitrogen-rich column overhead at a higher purity.

[0033] The heat exchange duty for the subcooling unit 52 is provided by a lower pressure nitrogen-rich vapor stream 56 composed of the lower pressure column nitrogen-rich vapor column overhead produced in the lower pressure column 16. The lower pressure nitrogen-rich vapor stream 56 is subsequently passed into and warmed within the main heat exchanger 12 to cool the compressed and purified air stream 10 and is discharged as a waste nitrogen stream 57 that itself can be taken as a product or be used in the regeneration of the pre-purifier.

[0034] The oxygen product is produced from the oxygen-rich liquid column bottoms 38 of the lower pressure column 16 in a conventional manner. In this regard, an oxygen-rich column bottoms stream 58 is withdrawn from the lower pressure column 16 and composed of the oxygen-rich liquid column bottoms 38 and pressurized by a pump 59. A part of a resulting pressurized liquid oxygen stream 60 is warmed through indirect heat exchange with a high pressure air stream 62 within main heat exchanger 12 to produce a pressurized oxygen product stream 64. High pressure air stream 62 constitutes between 30 and 40 percent of the air fed to such distillation column arrangement. Depending on the degree of pressurization imparted by pump 59, the resulting pressurized oxygen product stream 64 will be a vapor or a supercritical fluid. Although all of the pressurized liquid oxygen could be used for such purposes, another part of the resulting pressurized liquid oxygen as a stream 66 can be let down in pressure by a valve 68 and used to form a liquid oxygen product stream 70 for storage.

[0035] It is to be noted that other pressurized product stream could be used for the warming of the pressurized liquid oxygen. For example, nitrogen could be extracted from the warm end of the main heat exchanger, compressed and then used as the pressurized product stream to warm the pressurized liquid oxygen. The resulting liquid stream would then be reintroduced into the higher or lower pressure columns or both of such columns.

[0036] The indirect heat exchange between the high pressure air stream 62 and the part of the resulting pressurized liquid oxygen stream 60 produces liquid air 76. In this regard, after the high pressure air stream 62 has been partially cooled within main heat exchanger

12, the high pressure air stream 62 is divided into a first subsidiary high pressure air stream 72 and a second subsidiary high pressure air stream 74. The first subsidiary high pressure air stream 72 is fully cooled and forms a liquid air stream 76 which will typically have a temperature between 98 K and 103 K. The second subsidiary high pressure air stream 74 after having been partially cooled is expanded in a turboexpander 78 to produce an exhaust stream 80 that is introduced into the bottom region of the higher pressure column 14 to impart refrigeration.

[0037] As would occur to those skilled in the art, other methods could be used to generate refrigeration and therefore, all of the high pressure air stream 62 could be liquefied. In this regard, other options include: expanding a portion of the higher pressure nitrogen-rich vapor stream 42; expanding the compressed and purified air stream into the higher pressure column 14, expanding a portion of the compressed and purified air stream and introducing the exhaust into the lower pressure column 16; or expanding a nitrogen containing stream from the lower pressure column 16 after partial warming in subcooling unit 52 and the main heat exchanger 12. As would also be known, the shaft work of expansion may be imparted to the compression of the stream being expanded or used for purposes of compressing another process stream or generating electricity. Alternatively, liquid air stream 76 may be depressurized by way of a liquid turbine for purposes of generating additional refrigeration.

[0038] Liquid air stream 76 is divided into two portions 82 and 84 which are introduced into the lower pressure column 16 and the higher pressure column 14, respectively. Portion 82 of the liquid air stream 76 will typically constitute between 50 percent to 85 percent of the liquid air stream 76. This introduction of the liquid air into the distillation columns is effected by letting down the pressure of the two portions 82 and 84 by means of expansion valves 86 and 88, respectively. As can be appreciated, embodiments of the present invention are possible in which all of the liquid air stream 76 is introduced into the lower pressure column 16 or the higher pressure column 14 after having been let down in pressure. Additionally, it is also possible to subcool the liquid air stream 82 within subcooling unit 52.

[0039] In many instances the feed location of the liquid air 82 or the feed point for stream 26 (or any of the fluids generated from it) intended for the lower pressure column 16

resides at a considerable height, for instance, about 150 to 200 feet. In some instances a mechanical pump will be required to motivate the liquid air into its feed location. Alternatively, vapor lift can be generated through low level expansion or the introduction of pressurized gas, for example air. A further point is that liquid air stream may be directed to an intermediate location of the higher pressure column 14 and a liquid air stream may then be extracted at a comparable location, for example, the downcomer of a tray where trays are used in the column. The extracted stream may then be subcooled and fed to the lower pressure column 16 or in part to the lower pressure column 16 and an auxiliary column 124 to be discussed hereinafter in connection with Figure 2 or combined with an oxygen-enriched stream 122 to be discussed hereinafter in connection with the embodiment of the present invention shown in Figure 1.

[0040] As indicated above, the condensed nitrogen stream 43 can be divided into a first part of the condensed nitrogen-rich stream 44, a second part of the condensed nitrogen-rich stream 46 and a third part of the condensed nitrogen-rich stream 48. The second part of the condensed nitrogen-rich stream 46 can be subcooled within subcooling unit 52 and then let down in pressure by an expansion valve 90 to produce a liquid nitrogen product stream 92. The third part of the condensed nitrogen-rich stream 48 can be pumped by means of pump 94 and then warmed within main heat exchanger 12 to produce a pressurized nitrogen product stream 96.

[0041] In accordance with the present invention, oxygen recovery and therefore production of the oxygen products, for instance, oxygen product stream 58, is increased by increasing the liquid to vapor ratio in the lower pressure column in a manner that oxygen product purity is not compromised. As such, air separation plant 1 is able to produce its oxygen products at a greater rate without a degradation of oxygen purity or recovery. As indicated above, this is particularly problematical for an air separation plant that is producing both oxygen and nitrogen products and as stated above where the oxygen has a purity of 99.5 percent and greater. In air separation plant 1, production is increased by further processing at least part of the crude liquid oxygen column bottoms 24 of the higher pressure column 14 in a manner that such bottoms liquid is used to condense argon-enriched vapor above an argon stripping section of the lower pressure column 16 and then,

to produce subsidiary nitrogen-rich liquid reflux and an oxygen-enriched stream to be rectified within the lower pressure column 16.

[0042] More specifically, the crude liquid oxygen stream 26 is withdrawn from the higher pressure column 14, subcooled within subcooling unit 52 and then valve expanded within an expansion valve 100 to a pressure of between 25 psia and 45 psia. After the lowering of the temperature as a result of the expansion, the crude liquid oxygen stream 26 is introduced into an intermediate heat exchanger 102. Intermediate heat exchanger 102 is in flow communication with the lower pressure column 16 such that an argon-enriched vapor stream 104 is passed in indirect heat exchange with the crude liquid oxygen stream 26 causing the argon-enriched vapor stream 104 to form at least a partially condensed stream 106. Stream 106 is introduced back into the lower pressure column above a lowermost region of lower pressure column formed by mass transfer contacting elements 28. This region is where argon is stripped from downcoming liquid. The crude liquid oxygen stream 26 is partially vaporized within intermediate heat exchanger 102 to form a two phase stream 108 that typically can contain between 15 percent and 25 percent vapor. It is to be noted that intermediate heat exchanger could be positioned within lower pressure column 16; and in such case, an argon-enriched vapor stream 104 would not have to be withdrawn from and reintroduced into lower pressure column 16. The effect of the condensation of the argon-enriched vapor is to increase the liquid to vapor ratio within the lower pressure column which increases the efficiency by which argon is stripped from the descending liquid, thereby enhancing oxygen recovery. In this regard, the nitrogen concentration of argon-enriched vapor stream 104 or the argon-enriched vapor to be condensed within lower pressure column 16 should be between 0.1 mole percent and 5.0 mole percent nitrogen. This nitrogen concentration assures condensation of the argon-enriched vapor stream 104 by the crude liquid oxygen stream 25. As well known in the art, as the nitrogen concentration increases, the saturation temperature of the argon-enriched vapor stream 104 would become increasingly colder and the condensation of such stream with the crude liquid oxygen stream 25 would become impractical. In any case, the argon content of the argon-enriched vapor stream 104 will typically be between 7 and 12 percent by volume.

[0043] It is to be noted that the present invention encompasses possible embodiments in which the argon-enriched vapor stream 104 is only partially condensed. As can be appreciated, a partial condensation of stream 104 would require processing a larger volumetric flow of vapor and hence a larger exchanger. It is also to be mentioned although crude liquid oxygen stream 25 is most preferably subcooled, possible embodiments of the present invention exist where such subcooling is not employed. Such a modification would tend to reduce the vaporized fraction of stream 108 and hence the quantity of nitrogen rich reflux that could be generated.

[0044] A phase separator 110 is connected to the intermediate heat exchanger 102 to disengage liquid and vapor phases from the two-phase stream 108 and thereby to form a vapor phase stream 112 and a liquid phase stream 114. An auxiliary heat exchanger 116 connected to the phase separator 110 and configured to partially vaporize the liquid phase stream 114 after expansion within an expansion valve 117 through indirect heat exchange with the vapor phase stream 112. Liquid phase stream 114 after expansion through valve 117 has a pressure that is comparable with that of the lower pressure column or between 15 psia and 20 psia. As a result of the heat exchange, the vapor phase stream 112 is condensed to form a supplemental nitrogen-rich reflux stream 118 that is let down in pressure by expansion valve 120 and introduced into the lower pressure column 16 as supplemental reflux to also increase the liquid to vapor ratio within such column and help to increase oxygen recovery. It is possible to only introduce a portion of the supplemental nitrogen-rich reflux stream into the lower pressure column. In such case, another portion could be pumped and introduced into the higher pressure column 14.

[0045] Partial vaporization of the liquid phase stream 114 forms an oxygen-enriched stream 122 that typically can contain 40 to 50 mole percent vapor and an oxygen concentration in the neighborhood of about 45 to 50 mole percent. The oxygen-enriched stream 122 is introduced into the lower pressure column 16 above the location at which the argon-enriched vapor 104 is withdrawn for condensation; preferably 2 to 6 stages above.

[0046] While it is advantageous to employ a full flow of the crude liquid oxygen stream 26 through the intermediate heat exchanger 102, this need not be the case. In particular, only a portion of the crude liquid oxygen stream 26 may be employed for this purpose;

and a portion of the crude liquid oxygen stream 26 may be fed directly to the lower pressure column 16 at an elevation thereof above which the oxygen-enriched stream 122 enters such column. Alternatively, the liquid phase stream 114 may be split so that a portion of the liquid may then be directed to an elevated location of the lower pressure column 16, above a location at which the remaining portion is introduced after having passed through auxiliary heat exchanger 116.

[0047] Although the supplemental nitrogen-rich reflux stream 118 is illustrated as being directed to the lower pressure column 16, it may be advantageous to further subcool this stream within subcooling unit 52 along with the part of the liquid air stream 82.

Alternatively these liquid streams may be combined prior to column entry. Alternatively, the supplemental nitrogen-rich reflux stream may be fed to a column location different than that of liquid air stream 82. The supplemental nitrogen-rich reflux stream may be pressurized by a combination of static head and/or mechanical pump prior to entry into either the higher or lower pressure columns 14 and 16.

[0048] With reference to Figure 2, an auxiliary column 124 is provided that contains mass transfer contacting elements 126 and 128. Auxiliary column 124 is connected to the phase separator 110 such that the vapor phase stream 112 is introduced into a bottom region of the auxiliary column 124. The first part of the liquid air stream 82 is divided into first and second subsidiary liquid air streams 130 and 132. First subsidiary liquid air stream 130 is valve expanded in an expansion valve 134 and introduced into the lower pressure column 16 and second subsidiary liquid air stream 132 is valve expanded in an expansion valve 136 and then, is introduced into an intermediate location of the auxiliary column 124. An oxygen containing bottoms liquid 138 and a supplemental nitrogen-rich vapor column overhead are formed within the auxiliary column 124. An auxiliary column heat exchanger 140 is connected to the auxiliary column 124, the phase separator 110 and the bottom region of the auxiliary column 124 are connected such that the liquid phase stream 114 is combined with an oxygen containing bottoms liquid stream 142 formed of the oxygen containing bottoms liquid 138. Alternatively, stream 108 could be passed directly into the base of column 124. The resulting combined liquid stream 144 is valve expanded in an expansion valve 146 and is then passed in indirect heat exchange with a supplemental nitrogen-rich vapor column overhead stream 148 within the auxiliary

column heat exchanger 140. This condenses the supplemental nitrogen-rich vapor stream 148 and partially vaporizes the combined liquid stream 144 to form an oxygen-enriched stream 122', a supplementary nitrogen-rich reflux stream 118' and an auxiliary column reflux stream 150.

[0049] The oxygen-enriched stream 122' is introduced into the lower pressure column 16. The supplementary nitrogen-rich reflux stream 118' has about the same oxygen content as the impure nitrogen-rich liquid stream 50 and can be combined with the same and introduced into the lower pressure column 16 as reflux after expansion in a valve 119. As can be appreciated supplementary nitrogen-rich reflux stream 118' could be separately introduced into the lower pressure column 16. The auxiliary column reflux stream 150 is re-introduced into the auxiliary column 124 as reflux for such column.

[0050] Although not illustrated, auxiliary column 124 may be designed with staging sufficient deliver a high purity nitrogen stream containing less than 10 parts per million by volume of oxygen. In such situations a portion of the nitrogen derived overhead may be taken as a product gas or liquid. For instance, the pressurized product fraction proceeding through pump 94 could be derived from auxiliary column 124. Alternatively, a gaseous product stream can be taken from auxiliary column 124 and sequentially warmed in subcooling unit 52 and main heat exchanger 12. Alternatively, a high purity nitrogen liquid from auxiliary column 124 may be subcooled in subcooling unit 52 and directed to a top hat section incorporated into the lower pressure column 16.

[0051] There exists a substantial excess of crude liquid oxygen column bottoms liquid 24 that could be potentially be evaporated with undue affect upon the distillation occurring within the lower pressure column 16. As such other streams can be effectively cooled in either the intermediate heat exchanger 102 or the associated heat exchangers, namely auxiliary heat exchanger 116 shown in Figure 1 or the auxiliary column heat exchanger 140 shown in Figure 2. As an example, liquid air destined for the lower pressure column 16 or to the auxiliary column 124 could be advantageous cooled in either of these exchangers. The net effect would be a reduction in the flash losses upon entry into the lower pressure column 16 and the auxiliary column 124 with an accompanying improvement in product recovery.

[0052] While the present invention has been described with reference to a preferred embodiment, as will occur to those skilled in the art, numerous changes, additions and omission can be made without departing from the spirit and scope of the present invention as set forth in the appended claims.

I Claim:

1. A method of separating air to produce an oxygen product, said method comprising:
separating the air in a cryogenic rectification process having a higher pressure column and a lower pressure column operatively associated with one another in a heat transfer relationship to produce nitrogen-rich reflux for the higher pressure column and the lower pressure column and producing the oxygen product from an oxygen-rich liquid column bottoms of the lower pressure column;

conducting the cryogenic rectification process such that a crude liquid oxygen stream formed of a crude liquid oxygen column bottoms produced in the higher pressure column is partially vaporized against at least partially condensing an argon-enriched vapor produced in the lower pressure column, a supplemental nitrogen-rich reflux stream and an oxygen-enriched stream having a greater oxygen content than the crude liquid oxygen stream are both formed from a two-phase stream produced, at least in part, from the crude liquid oxygen stream after partial vaporization thereof, and the oxygen-enriched stream and at least part of the supplemental nitrogen-rich reflux stream are fed into the lower pressure column;

the argon-enriched vapor at least partially condensed at a location of the lower pressure column where the argon-enriched vapor has a nitrogen concentration of between 0.1 mole percent and 5.0 mole percent and resulting condensate combines with downcoming liquid of the lower pressure column thereby increasing the liquid to vapor ratio in a lowermost section of the lower pressure column; and

the further oxygen-enriched stream and at least a portion of the supplemental nitrogen-rich liquid stream being fed at successively higher locations of the lower pressure column and above the location of the lower pressure column at which the argon-enriched vapor is at least partially condensed.

2. The method of claim 1, wherein the oxygen product is produced from an oxygen-rich liquid column bottoms of the lower pressure column by:

pumping at least part of an oxygen-rich column bottoms stream withdrawn from the lower pressure column and composed of the oxygen-rich liquid column bottoms to produce a pressurized liquid oxygen stream;

warming at least part of the pressurized liquid oxygen stream through indirect exchange with a high pressure process stream such that at least part of the high pressure process stream is liquefied and the oxygen product is formed from the pressurized liquid oxygen stream after having been warmed; and

introducing the at least part of the high pressure stream after liquefaction into at least one of the higher pressure column and the lower pressure column.

3. The method of claim 2, wherein:

the crude liquid oxygen stream is valve expanded and partially vaporized and then is passed in indirect heat exchange with the argon-enriched vapor;

the supplemental nitrogen-rich reflux stream and the oxygen-enriched stream are formed by disengaging liquid and vapor phases from the two-phase stream to form a vapor phase stream and a liquid phase stream, valve expanding the liquid phase stream and partially vaporizing the liquid phase stream in indirect heat exchange with the vapor phase stream thereby condensing the vapor phase stream to form the supplemental nitrogen-rich reflux stream and the oxygen-enriched stream from the liquid phase stream after the liquid phase stream has been partially vaporized;

the at least part of the nitrogen-rich reflux stream is valve expanded and at least in part introduced into the lower pressure column; and

the oxygen-enriched stream is introduced into the lower pressure column.

4. The method of claim 2, wherein:

the crude liquid oxygen stream is valve expanded, is partially vaporized and then is passed in indirect heat exchange with the argon vapor stream;

the high pressure process stream is a high pressure air stream that after liquefaction forms a liquid air stream;

at least part of the liquid air stream is divided into a first subsidiary liquid air stream and a second subsidiary liquid air stream;

the first subsidiary liquid air stream is valve expanded and introduced into the lower pressure column;

the supplemental nitrogen-rich reflux stream and the oxygen-enriched stream are formed by:

disengaging liquid and vapor phases from the two-phase stream to form a vapor phase stream and a liquid phase stream;

introducing the vapor phase stream into a bottom region of an auxiliary column and the second subsidiary liquid air stream into an intermediate location of the auxiliary column to form an oxygen containing bottoms liquid and a supplemental nitrogen-rich vapor column overhead within the auxiliary column;

forming a combined oxygen-enriched stream by combining the liquid phase stream with an oxygen containing bottoms liquid stream formed of the oxygen containing bottoms liquid;

condensing a supplemental nitrogen-rich vapor column overhead stream formed of the supplemental nitrogen-rich vapor column overhead through indirect heat exchange with the combined liquid stream after the valve expansion thereof, thereby partially vaporizing the combined liquid stream and forming the oxygen-enriched stream and the supplementary nitrogen-rich reflux stream and also an auxiliary column reflux stream from the nitrogen-rich vapor column overhead stream after having been condensed; and

refluxing the auxiliary column with the auxiliary column reflux stream; and

the at least part of the subsidiary nitrogen-rich reflux stream is valve expanded and introduced into the lower pressure column.

5. The method of claim 3, wherein the high pressure process stream is a high pressure air stream that after liquefaction forms a liquid air stream.

6. The method of claim 4 or claim 5, wherein the liquid nitrogen reflux to the higher pressure column and the lower pressure column is produced by:

condensing a higher pressure nitrogen-rich vapor stream composed of higher pressure nitrogen-rich vapor produced in the higher pressure column through indirect heat

exchange with the oxygen-rich liquid column bottoms of the lower pressure column, thereby to produce a condensed nitrogen-rich stream;

refluxing the higher pressure column with at least part of the condensed nitrogen-rich stream; and

removing an impure nitrogen-rich liquid stream from the higher pressure column, subcooling and valve expanding the impure nitrogen-rich liquid stream and refluxing the lower pressure column with the impure nitrogen-rich liquid stream.

7. The method of claim 6, wherein:

a lower pressure nitrogen-rich vapor stream composed of a lower pressure nitrogen-rich vapor produced in the lower pressure column is removed from the lower pressure column;

the lower pressure nitrogen-rich vapor stream passes in indirect heat exchange with the crude liquid oxygen stream and the impure nitrogen-rich liquid stream to subcool the crude liquid oxygen stream and the impure nitrogen-rich liquid stream;

the lower pressure nitrogen-rich vapor stream is passed in indirect heat exchange with a compressed and purified air stream composed of the air to be separated; and

the compressed and purified air stream after having been cooled is introduced into a bottom region of the higher pressure column.

8. The method of claim 7, wherein:

after the high pressure air stream has been partially cooled, the high pressure air stream is divided into a first subsidiary high pressure air stream and a second subsidiary high pressure air stream;

the first subsidiary high pressure air stream is fully cooled and forms the liquid air stream;

the second subsidiary high pressure air stream after having been partially cooled is expanded in a turboexpander and introduced into the bottom region of the higher pressure column to impart refrigeration into the cryogenic rectification process.

9. The method of claim 8, wherein:

the higher pressure column is refluxed with a first part of the condensed nitrogen-rich stream;

a second part of the condensed nitrogen-rich stream is passed in indirect heat exchange with the lower pressure nitrogen-rich vapor stream along with the impure nitrogen-rich liquid stream and the crude liquid oxygen stream to form a liquid nitrogen product stream;

a third part of the condensed nitrogen-rich stream is pressurized and warmed through indirect heat exchange with the high pressure air stream along with the oxygen-rich column bottoms stream to form a pressurized nitrogen product stream.

10. An apparatus for separating air to produce an oxygen product, said apparatus comprising:

an air separation plant configured to separate the air through cryogenic rectification and having a higher pressure column and a lower pressure column operatively associated with one another in a heat transfer relationship to produce nitrogen-rich reflux for the higher pressure column and the lower pressure column and means for producing the oxygen product from an oxygen-rich liquid column bottoms of the lower pressure column;

the operative association of the lower pressure column and the higher pressure column including: means for partially vaporizing a crude liquid oxygen stream composed of a crude liquid oxygen column bottoms of the higher pressure column against at least partially condensing an argon-enriched vapor produced in the lower pressure column, means for producing a supplemental nitrogen-rich reflux stream and an oxygen-enriched stream having a greater oxygen content than the crude liquid oxygen column bottoms from a two-phase stream produced, at least in part, from the crude liquid oxygen stream after the partial vaporization thereof;

the argon-enriched vapor at least partially condensed at a location of the lower pressure column where the argon-enriched vapor has a nitrogen concentration between 0.1 and 5.0 mole percent and the resulting condensate will combine with downcoming liquid of the lower pressure column and increase a liquid to vapor ratio in a lowermost section of the lower pressure column; and

the supplemental nitrogen-rich reflux stream and the oxygen-enriched stream producing means connected to the lower pressure column such that the oxygen-enriched stream and at least part of the supplemental nitrogen-rich liquid stream are fed at successively higher locations of the lower pressure column and above the location of the lower pressure column at which the argon-enriched vapor is at least partially condensed.

11. The apparatus of claim 10, wherein the oxygen product producing means comprises:

a pump connected to the lower pressure column such that at least part of an oxygen-rich column bottoms stream withdrawn from the lower pressure column and composed of the oxygen-rich liquid column bottoms is pressurized by the pump to produce a pressurized liquid oxygen stream;

a main heat exchanger in flow communication with the pump and configured to warm at least part of the pressurized liquid oxygen stream through indirect exchange with a high pressure process stream such that at least part of the high pressure process stream is liquefied and the oxygen product is formed from the pressurized liquid oxygen stream after having been warmed; and

at least the lower pressure column is in flow communication with the main heat exchanger such that at least part of the high pressure process stream after having been liquefied is introduced into at least one of the higher or lower pressure column.

12. The apparatus of claim 11, wherein:

the means for partially vaporizing the crude liquid oxygen stream comprises an intermediate heat exchanger in flow communication with the lower pressure column and configured to pass the crude liquid oxygen stream in indirect heat exchange with the argon enriched vapor;

the supplemental nitrogen-rich reflux stream and the oxygen-enriched stream producing means comprises:

a phase separator connected to the intermediate heat exchanger to disengage liquid and vapor phases from the two-phase stream and thereby to form a vapor phase stream and a liquid phase stream; and

an auxiliary heat exchanger connected to the phase separator and configured to partially vaporize the liquid phase stream in indirect heat exchange with the vapor phase stream thereby condensing the vapor phase stream and forming the supplemental nitrogen-rich reflux stream from the vapor phase stream after condensation thereof and the oxygen-enriched stream from the liquid phase stream after partial vaporization of the liquid phase stream;

the auxiliary heat exchanger is connected to the lower pressure column such that the oxygen-enriched stream and the at least part of the supplemental nitrogen-rich reflux stream are introduced into the lower pressure column; and

an arrangement of expansion valves are positioned for expanding: the crude liquid oxygen stream before being partially vaporized; the liquid phase stream prior to the indirect heat exchange with the vapor phase stream; and that at least part of the nitrogen-rich reflux stream before being introduced into the lower pressure column.

13. The apparatus of claim 11, wherein:

the means for partially vaporizing the crude liquid oxygen stream comprises an intermediate heat exchanger in flow communication with the lower pressure column and configured to pass the crude liquid oxygen stream in indirect heat exchange with the argon enriched vapor;

the high pressure process stream is a high pressure air stream that after liquefaction forms a liquid air stream;

the lower pressure column is in flow communication with the main heat exchanger such that the at least part of the liquid air stream is divided into a first subsidiary liquid air stream that is introduced into the lower pressure column and a second subsidiary liquid air stream;

the supplemental nitrogen-rich reflux stream and the oxygen-enriched stream producing means comprises:

a phase separator connected to the intermediate heat exchanger such that liquid and vapor phases from the two-phase stream are disengaged to form a vapor phase stream and a liquid phase stream;

an auxiliary column connected to the phase separator and the main heat exchanger such that the vapor phase stream is introduced into a bottom region of the auxiliary column and the second subsidiary liquid air stream is introduced into an intermediate location of the auxiliary column to form an oxygen containing bottoms liquid and a supplemental nitrogen-rich vapor column overhead within the auxiliary column; and

an auxiliary column heat exchanger connected to the auxiliary column and the phase separator such that: the liquid phase stream is combined with an oxygen containing bottoms liquid stream formed of the oxygen containing bottoms liquid; the combined liquid stream passes in indirect heat exchange with a supplemental nitrogen-rich vapor column overhead stream formed of the supplemental nitrogen-rich vapor column overhead, thereby condensing the supplemental nitrogen-rich vapor stream and partially vaporizing the combined liquid stream to form the oxygen-rich reflux stream and the supplemental nitrogen-rich reflux stream and also, an auxiliary column reflux stream; and the auxiliary column reflux stream refluxes the auxiliary column; and

an arrangement of expansion valves is positioned for expanding: the crude liquid oxygen stream before being partially vaporized; the first subsidiary liquid air stream prior to being introduced into the lower pressure column; the combined liquid stream prior to passing into the auxiliary column heat exchanger; and the at least part of the subsidiary nitrogen-rich liquid stream prior to introduction into the lower pressure column.

14. The apparatus of claim 12 wherein the high pressure process stream is a high pressure air stream that after liquefaction forms a liquid air stream.

15. The apparatus of claim 13 or claim 14, wherein:

a condenser reboiler is connected to the higher pressure column and the lower pressure column such that a higher pressure nitrogen-rich vapor stream composed of high pressure nitrogen-rich vapor produced in the higher pressure column is condensed through indirect heat exchange with the oxygen-rich liquid column bottoms of the lower pressure column, thereby to produce a condensed nitrogen-rich stream;

the higher pressure column is connected to the condenser reboiler such that the higher pressure column is refluxed with at least part of the condensed nitrogen-rich stream; and

the lower pressure column is connected to the higher pressure column such that an impure nitrogen-rich liquid stream is removed from the higher pressure column and introduced into the lower pressure column;

a subcooling unit is positioned between the higher pressure column and the lower pressure column such that the impure nitrogen-rich liquid stream is subcooled prior to being introduced into the lower pressure column; and

the arrangement of expansion valves also includes an expansion valve positioned between the subcooling unit and the lower pressure column such that the impure nitrogen-rich liquid stream is subcooled prior to being introduced into the lower pressure column.

16. The apparatus of claim 15, wherein:

the subcooling unit is connected to the lower pressure column and the higher pressure column and is configured such that a lower pressure nitrogen-rich vapor stream composed of a lower pressure nitrogen-rich vapor produced in the lower pressure column passes in indirect heat exchange with the crude liquid oxygen stream and the impure nitrogen-rich liquid stream to subcool the crude liquid oxygen stream and the impure nitrogen-rich liquid stream;

the main heat exchanger connected to the subcooling unit such that the lower pressure nitrogen-rich vapor stream, after having passed through the subcooling unit, is passed in indirect heat exchange with a compressed and purified air stream composed of the air to be separated; and

the main heat exchanger is connected to the higher pressure column such that a compressed and purified air stream after having been cooled in the main heat exchanger is introduced into a bottom region of the higher pressure column.

17. The apparatus of claim 15, wherein:

the main heat exchanger is configured such that after the high pressure air stream has been partially cooled, the high pressure air stream is divided into a first subsidiary

high pressure air stream that is fully cooled and forms the liquid air stream and a second subsidiary high pressure air stream that is partially cooled prior to discharge from the main heat exchanger; and

a turboexpander is positioned between the main heat exchanger and the higher pressure column such that the second subsidiary high pressure air stream is expanded in a turboexpander and introduced into the bottom region of the higher pressure column to impart refrigeration into the air separation plant.

18. The apparatus of claim 17, wherein:

the higher pressure column is connected to the condenser reboiler such that the higher pressure column is refluxed with a first part of the condensed nitrogen-rich stream;

the subcooling unit is connected to the condenser reboiler such that a second part of the condensed nitrogen-rich stream is passed in indirect heat exchange with the lower pressure nitrogen-rich vapor stream along with the impure nitrogen-rich liquid stream and the crude liquid oxygen stream to form a liquid nitrogen product stream;

another pump is positioned between the main heat exchanger and the condenser reboiler such that a third part of the condensed nitrogen-rich stream is pumped and then warmed in the main heat exchanger through indirect heat exchange with the high pressure air stream along with the oxygen-rich column bottoms stream to form a pressurized nitrogen product stream.

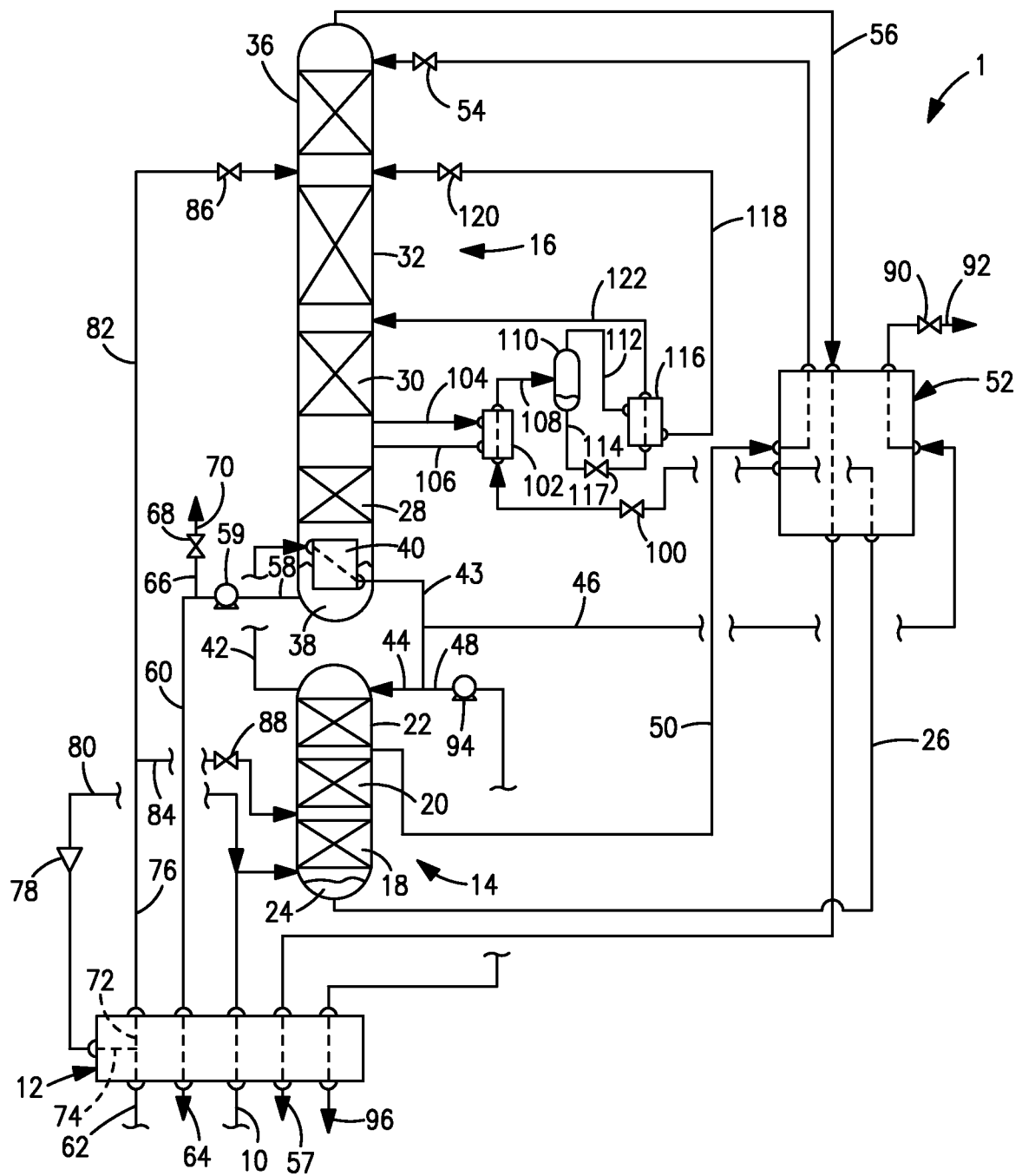
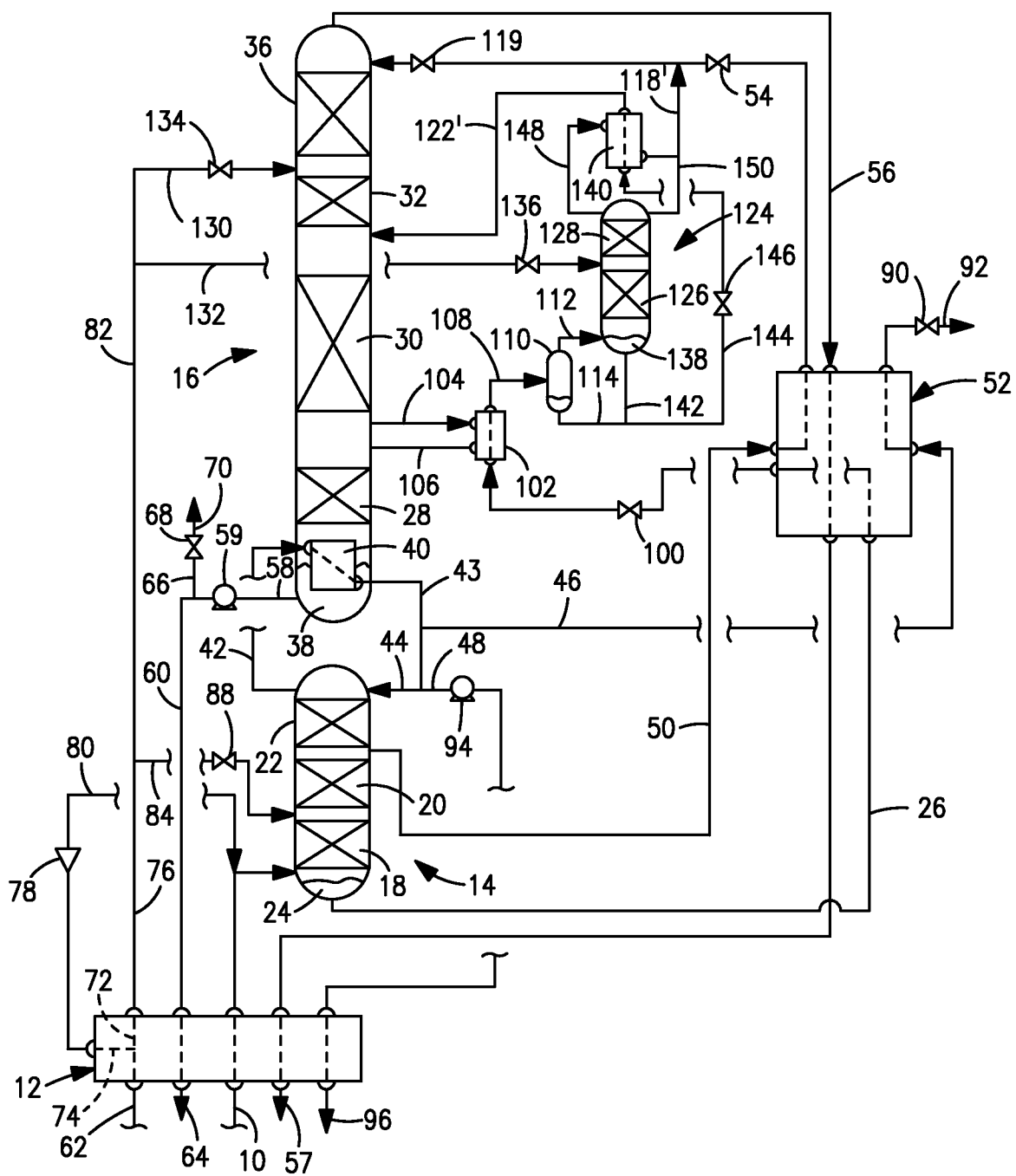


FIG. 1

**FIG. 2**