FEED COMPRESSION METHOD AND APPARATUS FOR AIR SEPARATION PROCESS

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ABSTRACT
A method and apparatus for separating air to produce a gaseous oxygen product in which the air is separated in an air separation plant to conduct a cryogenic rectification process that utilizes higher and lower pressure compressed air streams. The higher and lower pressure compressed air streams are generated in two multistage compressors linked together so that the lower pressure compressed air stream is produced from intermediate stages and the higher pressure compressed air stream is produced from higher pressure compression stages. During turn-down operational conditions, one of the two multistage compressors can be shut down to decrease the flow of air and therefore, the production of the oxygen product.
FEED COMPRESSION METHOD AND APPARATUS FOR AIR SEPARATION PROCESS

FIELD OF THE INVENTION

[0001] The present invention relates to a method and apparatus for separating air for producing an oxygen product in which the air is separated by cryogenic rectification within an air separation plant that utilizes higher and lower pressure air streams. More particularly, the present invention relates to such a method and apparatus in which the air is compressed in two multistage compressors that are linked together to produce the higher pressure air stream from higher pressure stages and the lower pressure air stream from lower pressure intermediate stages and where one of the two multistage compressors can be turned off during turn-down operational conditions to decrease the flow of compressed air to the plant and therefore, production of the oxygen product.

BACKGROUND OF THE INVENTION

[0002] A recent development in the field of air separation is the requirement to produce large quantities of low purity oxygen for use in the combustion of coal in connection with electrical power generation and carbon capture. Such applications can require as much as 10,000 tons per day of oxygen that is supplied by two or more air separation plants. In order for such power plants to be practical, it is necessary that the power consumed by the air separation plants is as low as possible. Furthermore, since power plants can commonly operate at fractional loads, it is also important for the air separation plants that are used in connection with such power plants to also have a turn-down capability in which the air separation plant is able to efficiently supply the low purity oxygen by having a low power consumption during times that the power plant is operating at less than full capacity.

[0003] Typically, an air separation plant can operate efficiently at no lower than 75 to 80 percent of full capacity. Below this the power consumption of the air separation unit is nearly constant because the power expended in compressing the air for the air separation plant has not changed, even where the air flow to the plant has been substantially decreased due to compressor surge limitations. Therefore, the problem in efficient turn-down operation for the air separation plant centers on the compression equipment that is necessary to compress the air for the plant.

[0004] U.S. Pat. No. 4,895,583 discloses an air separation plant of the type that uses both higher and lower pressure compressed air stream and that is designed to produce low purity oxygen. The air is compressed and purified in two compressors and associated purification units to produce a higher pressure compressed and purified air stream and a lower pressure compressed and purified air stream. The higher pressure compressed and purified air stream is introduced into a first separation zone contained in a higher pressure column of the distillation column system for rectification. The resulting kettle liquid produced in the first separation zone is subcooled and introduced into a second separation zone formed in an upper section of the lower pressure column for further refinement. A lower portion of the second separation zone, situated at an intermediate location of the lower pressure column, is reboiled by removing a liquid stream at such location that constitutes a portion of the down coming liquid and vaporizing such stream through indirect heat exchange with a nitrogen-rich vapor produced as column overhead in the higher pressure column. The vaporized stream is returned to the lower pressure column to a stage below that at which the liquid stream is withdrawn. The resulting condensed nitrogen-rich vapor is used to reflux the first and second separation zones contained in the higher pressure column and the lower pressure column. An oxygen-rich column bottoms liquid collected in a third separation zone located in a lower stripping section of the lower pressure column. The bottoms liquid is vaporized through indirect heat exchange with the lower pressure compressed and purified air stream in a condenser to produce liquid air and an oxygen-rich vapor that is in part returned to the lower section of the lower pressure column and in part warmed and taken as the oxygen product. The liquid air is introduced into the higher pressure column and the lower pressure column as intermediate reflux.

[0005] U.S. Pat. No. 5,337,576 discloses an air separation process also having three separation zones contained in higher and lower pressure columns. In this patent, the air is compressed and purified to produce a higher pressure compressed and purified air stream and a lower pressure compressed and purified air stream. The lower pressure compressed and purified air stream is introduced into a first separation zone located in a higher pressure column for rectification to produce a kettle liquid as a column bottoms and a nitrogen-rich vapor as a column overhead. The nitrogen-rich vapor is condensed through indirect heat exchange with a kettle liquid stream composed of the kettle liquid. The kettle liquid is partially vaporized to produce liquid and vapor phases that are introduced into a bottom region of a second separation zone located in the a lower pressure column for further refinement and the condensed nitrogen-rich vapor is used to reflux the first and second separation zones located in the higher pressure column and an upper section of the lower pressure column. Part of the higher pressure compressed and purified air stream reboils a third separation zone located in a lower section of the lower pressure column to produce liquid air that is used to form part of an intermediate reflux for the first separation zone and the second separation zone situated in the higher pressure column and the lower pressure column. Another part of the higher pressure compressed and purified air stream is further compressed and used to vaporize an oxygen-rich liquid removed from the third separation zone, after pumping, to produce the oxygen product. The resulting liquid air is combined with the liquid air produced as a result of reboiling the lower section of the lower pressure column is also used in forming the intermediate reflux.

[0006] As will be discussed, the present invention provides a method and apparatus for separating air that, among other advantages, incorporates a compression system that allows for a greater operational efficiency during turn-down of compressors used in compressing the air than in the prior art.

SUMMARY OF THE INVENTION

[0007] The present invention provides a method of separating air to produce a gaseous oxygen product. In accordance with such method, the air is separated in a cryogenic rectification process that is configured to produce an oxygen-rich stream by cryogenically rectifying the air within a distillation column system and warming the oxygen-rich stream, thereby to produce the gaseous oxygen product. The cryogenic rectification process utilizes a first compressed air stream and a second compressed air stream having a lower pressure than the first compressed air stream. The first compressed air stream and the second compressed air stream are produced to feed the cryogenic rectification process by compressing the
air in two multistage compressors linked together such that during a normal mode of operation, a higher pressure air stream is produced from higher pressure stages of the two multistage compressors and a lower pressure air stream is produced from lower pressure intermediate stages of the two multistage compressors. The heat of compression is removed from the higher pressure air stream and the lower pressure air stream and the higher pressure air stream are purified to produce a higher pressure compressed and purified air stream and a lower pressure compressed and purified air stream. The higher pressure air stream is formed from at least part of the higher pressure compressed and purified air stream and the lower pressure air stream is formed from at least part of the lower pressure compressed and purified air stream. The cryogenic rectification process is able to be operated in a turn-down mode of operation by turning off one of the two multistage compressors and producing the higher pressure air stream and the lower pressure air stream from higher and lower pressure intermediate stages, respectively, of the other of the two multistage compressors, thereby decreasing air flow to the cryogenic rectification process and therefore, production of the oxygen-rich stream and the oxygen product.

[0008] The first compressed air stream can be formed from the lower pressure compressed and purified air stream and the second compressed air stream can be formed from a first part of the higher pressure compressed and purified air stream. A second part of the higher pressure compressed and purified air stream is further separately compressed in a booster compressor to produce a boosted pressure air stream that is partially cooled and then expanded to produce an exhaust stream. The exhaust stream is introduced into the distillation column system to impart refrigeration into the cryogenic rectification process.

[0009] The air contained in the first compressed air stream can be rectified in a first separation zone of a distillation column system to produce a klette liquid and a nitrogen-rich vapor. A klette liquid stream composed of the klette liquid is introduced into a second separation zone of the distillation column system for further refinement. The second separation zone operates at a lower operational pressure than the first separation zone. Down coming liquid entering a bottom region of the second separation zone is partly vaporized through indirect heat transfer with a nitrogen-rich vapor stream composed of the nitrogen-rich vapor produced in the first separation zone, thereby condensing the nitrogen-rich vapor stream and forming reflux for the first separation zone and the second separation zone and a crude oxygen liquid from residual liquid not vaporized through the indirect heat exchange. A crude oxygen liquid stream composed of the crude oxygen liquid is stripped in a third separation zone of the distillation column system operating at the lower operational pressure such that a nitrogen containing vapor and an oxygen-rich liquid are produced. The oxygen-rich liquid has a lower nitrogen content than the crude oxygen liquid. A nitrogen containing vapor stream composed of the nitrogen containing vapor is introduced into the second separation zone and the third separation zone is reboiled with the second compressed air stream to form a liquid air stream. Intermediated reflux streams, composed at least in part from the liquid air stream, are introduced into the first separation zone and the second separation zone and the oxygen-rich stream is withdrawn from the third separation zone and is composed of the oxygen-rich liquid.

[0010] In a specific embodiment of the present invention, a third part of the higher pressure compressed and purified air stream can be divided into two subsidiary streams that during the normal mode of operation are further separately compressed within two additional booster compressors and recombined to produce a further compressed third part of the compressed and purified air stream and during the turn-down mode of operation, the third part of the higher pressure compressed and purified air stream is further compressed within one of the two additional booster compressors to form the further compressed third part of the compressed and purified air stream with the other of the two additional booster compressors turned off. The further compressed third part of the compressed and purified air stream is fully cooled and the oxygen-rich stream is vaporized and warmed in part through indirect heat exchange with the further compressed third part of the compressed and purified air stream, thereby producing further liquid air. Intermediate reflux is introduced in the first separation zone and the second separation zone by subcooling a further liquid air stream composed of the further liquid air and a liquid air stream, composed of the liquid air produced in reboiling the third separation zone, through indirect heat exchange with a waste nitrogen stream produced in the second separation zone prior to the waste nitrogen stream being fully warmed, part of the further liquid air stream is valor expanded and combined with the liquid air stream to produce a first intermediate reflux stream which is further valor expanded and introduced into the second separation zone and introducing a second intermediate reflux stream that is introduced into the second separation zone. The kettle liquid stream is introduced into the second separation zone by subcooling the kettle liquid stream through indirect heat exchange with the waste nitrogen stream prior to being fully warmed, valor expanding the kettle liquid stream and introducing the kettle liquid stream into the second separation zone. A first reflux stream composed of part of the condensed nitrogen-rich vapor refluxes the first separation zone and a second reflux stream composed of another part of the condensed nitrogen-rich vapor is subcooled through indirect heat exchange with the waste nitrogen stream, valor expanded and refluxes the second separation zone. The oxygen-rich stream can be pumped prior to the oxygen-rich stream being vaporized and warmed through the indirect heat exchange with the further compressed third part of the compressed and purified air stream.

[0011] In any embodiment of the present invention, the distillation column system can have a higher pressure distillation column that houses the first separation zone, a lower pressure distillation column that houses the second separation zone and a side stripping column that houses the third separation zone. The kettle liquid stream is introduced into the second separation zone in the rectification column.

[0012] In another aspect of the present invention, an apparatus is provided for producing a gaseous oxygen product. In accordance with such aspect of the present invention, an air separation plant is configured to produce an oxygen-rich stream. The air separation plant is of the type that utilizes a first compressed air stream and a second compressed air stream and has a main heat exchanger to cool the first compressed air stream and the second compressed air stream. A distillation column system is connected to the main heat exchanger to rectify the air contained in the first compressed air stream and the second compressed air stream, thereby to produce the oxygen-rich stream and to return the oxygen-rich stream to the main heat exchanger such that the oxygen-rich stream is fully warmed to produce the gaseous oxygen product. A compression system is connected to a purification
system to produce the first compressed air stream and the second compressed air stream. The compression system has two multistage compressors linked together such that during a normal mode of operation, a higher pressure air stream is produced from higher pressure stages of the two multistage compressors and a lower pressure air stream is produced from lower pressure intermediate stages of the two multistage compressors and after-coolers connected to the higher pressure stages and the lower pressure intermediate stages remove heat of compression from the higher pressure air stream and the lower pressure air stream. The purification system is configured to purge the lower pressure air stream and the higher pressure air stream to produce a higher pressure compressed and purified air stream and a lower pressure compressed and purified air stream. The purification system is connected to the main heat exchanger such that the first compressed air stream is formed from at least part of the higher pressure compressed and purified air stream and the second compressed air stream is formed from at least part of the lower pressure compressed and purified air stream. A control system is provided for controlling the compression system such that the air separation plant is able to be selectively operated in the normal mode of operation and in a turn-down mode of operation in which one of the two multistage compressors is turned off and producing the higher pressure air stream and the lower pressure air stream from higher and lower pressure intermediate stages, respectively, of the other of the two multistage compressors, thereby decreasing air flow to the cryogenic rectification process and therefore, production of the oxygen-rich stream and the oxygen product.

The purification system can be connected to the main heat exchanger such that the first compressed air stream is formed from the lower pressure compressed and purified air stream and the second compressed air stream is formed from a first part of the higher pressure compressed and purified air stream. A booster compressor is connected to the purification system such that a second part of the higher pressure compressed and purified air stream is further compressed in the booster compressor to produce a boosted pressure air stream. The booster compressor is connected to the main heat exchanger and the main heat exchanger is configured such that the boosted pressure air stream is partially cooled within the main heat exchanger. A turbo-expander is positioned between the main heat exchanger and the distillation column system such that the boosted pressure air stream, after having been partially cooled, is expanded to produce an exhaust stream and the exhaust stream is introduced into the distillation column system to impart refrigeration into the cryogenic rectification process. The distillation column system can be provided with a first separation zone, a second separation zone and a third separation zone where the first separation zone has a higher operational pressure than the second separation zone. The first separation zone is connected to the main heat exchanger so as to receive the first compressed air stream for rectification. The second separation zone connected to the first separation zone such that a kettle liquid stream composed of kettle liquid produced in the first separation zone is introduced into the second separation zone for further refinement. A condenser-reboiler is connected to the second separation zone and the first separation zone such that a nitrogen-rich vapor stream produced in the first separation zone indirectly exchanges heat to all down-coming liquid flowing towards a bottom region of the second separation zone, thereby condensing the nitrogen-rich vapor stream and partly vaporizing the down-coming liquid to produce boil-up in the second separation zone and a crude oxygen liquid collected in the bottom region of the second separation zone from down-coming liquid that is not vaporized. The first separation zone and the second separation zone are in flow communication with the condenser reboiler such that reflux streams produced as a result of the condensing of the nitrogen-rich vapor stream are introduced into the first separation zone and the second separation zone. The third separation zone is connected to a bottom region of the second separation zone to receive a crude oxygen liquid stream, composed of the crude oxygen liquid and to return a nitrogen containing vapor stream back to the bottom region of the second separation zone. The third separation zone configured to strip the crude oxygen liquid, thereby to produce the nitrogen containing vapor stream and an oxygen-rich stream having a lower nitrogen content than the crude oxygen liquid. A reboiler is located in the third separation zone and in flow communication with the main heat exchanger so as to receive the second compressed air stream, thereby to reboil the third separation zone and to produce liquid oxygen. The first separation zone and the third separation zone are in flow communication with the reboiler such that at least one intermediate reflux stream produced, at least in part, of the liquid air is introduced into at least one of the first separation zone and the second separation zone as intermediate reflux and the main heat exchanger is in flow communication with the third separation zone such that the oxygen-rich stream warms form the oxygen product.

Two additional booster compressors can be positioned between the purification system and the main heat exchanger such that during the normal mode of operation a word part of the higher pressure compressed and purified air stream is divided into two further subsidiary streams that are separately compressed and combined to form a further compressed third part of the higher pressure compressed and purified air stream. The control system also controls the two additional booster compressors such that during the normal mode of operation both of the two additional booster compressors are in operation and in the turn-down mode of operation, the third part of the higher pressure compressed and purified air stream compressed within one of the two additional booster compressors to form the further compressed third part of the higher pressure compressed and purified air stream and the other of the two additional booster compressors is turned off. The main heat exchanger is configured such that the further compressed third part of the higher pressure compressed and purified air stream fully cools within the main heat exchanger and a vaporizer is connected between the main heat exchanger and a third separation zone such that the oxygen-rich stream is removed from the third separation zone as a liquid and vaporized and warmed in part through indirect heat exchange with the further compressed third part of the compressed and purified air stream, thereby to produce further liquid air. At least one subcooling unit is connected between the reboiler, the second separation zone and the vaporizer such that a further liquid air stream composed of the further liquid air and a liquid air stream, composed of the liquid air, are subcooled through indirect heat exchange with a waste nitrogen stream produced in the second separation zone, the at least one subcooling unit also connected to the main heat exchanger such that the waste nitrogen stream fully warms within the main heat exchanger. The second separation zone is connected to the at least one subcooling unit such that a part of the further liquid air stream combines with the liquid air stream to produce the interme-
diate reflux stream. The first separation zone and the second separation zone are in flow communication with the at least one subcooling unit such that a first intermediate reflux stream composed of part of the intermediate reflux stream is introduced into the second separation zone and a second intermediate reflux stream composed of a further part of the intermediate reflux stream is introduced into the first separation zone. The first separation zone is connected to the condenser reboiler such that a first of the reflux streams is introduced into the first separation zone and at least one subcooling unit is also connected to the higher pressure distillation column such that the kettle liquid stream subcools within the at least one subcooling unit through indirect heat exchange with the waste nitrogen stream and a second of the reflux stream subcools within the at least one subcooling unit through indirect heat exchange with the waste nitrogen stream. The second separation zone is connected to the at least one subcooling unit such that the second separation zone is refluxed with the second of the reflux streams. Expansion valves are positioned between the at least one subcooling unit and the second separation zone such that the part of the further liquid air stream is expanded prior to combining with the liquid air stream and the first intermediate reflux stream is expanded prior to entering the second separation zone, the second of the reflux streams is expanded prior to entering the first separation zone and the kettle liquid stream is expanded before introduction into the second separation zone.

[0016] In any embodiment of an apparatus of the present invention, the distillation column system can have a higher pressure distillation column that houses the first separation zone, a lower pressure distillation column that houses the second separation zone and a side stripping column that houses the third separation zone. The bottom region of the second separation zone is a sump in the lower pressure distillation column that contains the condenser reboiler.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] While the specification concludes with claims distinctly pointing out the subject matter that Applicant regards as his invention, it is believed that the invention will be better understood when taken in connection with the accompanying drawings in which:

[0018] FIG. 1 is a schematic of an apparatus designed to carry out a method in accordance with the present invention;

[0019] FIG. 2 is a schematic process flow diagram of an air separation plant that can be used in the apparatus shown in FIG. 1;

[0020] FIG. 3 is an alternative embodiment of FIG. 2;

[0021] FIG. 4 is an alternative embodiment of FIG. 2; and

[0022] FIG. 5 is an alternative embodiment of FIG. 2.

DETAILED DESCRIPTION

[0023] With reference to FIG. 1, an apparatus 1 is illustrated that is a schematic of an air separation plant in accordance with the present invention. Apparatus 1 incorporates a compression system 2 to compress the air, a purification system 3 to purify the air, a main heat exchanger and a distillation column system (designated by reference numbers 62 and 64, respectively, in FIG. 2) that is schematically grouped together in a box 4.

[0024] Compression system 2 incorporates two multistage compressors 10 and 12 to compress two feed air streams 14 and 16. Although not illustrated, each of the multistage compressors could incorporate interstage cooling with condensate removal. Additionally, each of the multistage compressors contain inlet guide vanes 11 and 13 to adjust the flow of the air into such compressors. The inlet guide vanes 11 and 13 are capable of adjusting the flow of the two feed air streams 14 and 16 into the two multistage compressors 10 and 12 to increase the flow from 100 percent down to a flow of between 70 percent and 80 percent. Where less flow is desired, part of the compressed air is vented or recirculated. Although not illustrated, each of the multistage compressors 10 and 12 could be provided with vent and recirculation lines to allow for such operation. Optionally, intermediate guide vanes may be incorporated into the two multistage compressors 10 and 12 (not shown) for optimal control of the lower pressure air streams 30 and 34 and higher pressure air streams 18 and 20 flow ratios.

[0025] The two multistage compressors 10 and 12 are linked together such that two subsidiary higher pressure air streams 18 and 20 produced from higher pressure final stages 22 and 24, respectively, are able to combine to produce a higher pressure air stream 26. Higher pressure air stream 26 passes through an aftercooler 28 to remove the heat of compression. Aftercooler 28 may include further air chilling means, such as mechanical or absorption chilling. Two subsidiary lower pressure air streams 30 and 32 are produced from lower pressure intermediate compression stages 34 and 36 that combine to produce a lower pressure air stream 38. The heat of compression is removed from the lower pressure air stream 38 by an aftercooler 40. Aftercooler 40 may include further air chilling means, such as mechanical or absorption chilling.

[0026] The higher pressure air stream 26 and the lower pressure air stream 38 are then purified within a purification system 3 that contains separate purification units 42 and 44 to produce a higher pressure compressed and purified air stream 46 and a lower pressure compressed and purified air stream 48. As well known in the art, purification units 42 and 44 are employed to remove higher boiling impurities such as water vapor, carbon dioxide and hydrocarbons from the air. Such units can incorporate adsorbent beds operating in an out of phase cycle that can be a combination of temperature and pressure swing adsorption to adsorb the higher boiling impurities in an on-line bed and to regenerate beds in an off-line status to desorb that higher boiling impurities and return the beds to an on-line status. Typically such regeneration will utilize waste nitrogen produced from the air separation unit 4. Although not illustrated, the purification could be accomplished in a single unit having three or more beds in which two beds are in operation and are therefore, in an on-line status at any given time with the third bed in an off-line status being regenerated. Such a unit is described in detail in U.S. Pat. No. 5,337,570.

[0027] A first compressed air stream 50 is produced from a first part of the higher pressure compressed and purified air stream 46. In the illustrated embodiment, all of the lower pressure compressed and purified air stream 48 forms a second compressed air stream 52. The second compressed air stream 52 and the first compressed air stream 50, having a higher pressure than the second compressed air stream 52, along with other air streams to be discussed, are cooled within the main heat exchanger and rectified within distillation column system to produce an oxygen product stream 54 and a waste nitrogen stream 56.
It is understood that the apparatus 1 can be of any design that uses higher and lower compressed air streams. As will be discussed, the first compressed air stream 50 is utilized in a specific embodiment described below for reboiling duty, although this does not have to be the case. For example, the first compressed air stream 50 could be used in heating an oxygen-rich liquid stream to produce an oxygen product stream. Alternatively, the first compressed air stream 50 could be partially cooled, expanded and introduced into a higher pressure column for purposes of imparting refrigeration. In specific embodiments of the present invention, to be discussed, the second compressed air stream 52 after having been cooled is introduced into a higher pressure column for rectification. However, such second compressed air stream 52 could be obtained as part of a sufficiently low pressure column, in particular, that it would be reheated into a lower pressure column. Additionally, not all of the lower pressure compressed and purified air stream 48 need be used in forming the second compressed air stream 52. In this regard, part of the lower pressure compressed and purified air stream could be used for other purposes, for example, turbine expansion and introduction into the low pressure column after partial cooling. Other elements shown in FIG. 1 will be discussed in more detail in FIG. 2 with respect to the more detailed description of an embodiment of the apparatus 1 and in particular, the main heat exchanger and the distillation column system.

The multistage compressors 10 and 12 of the compression system 2 are controlled by a controller 5 that are connected to the multistage compressors 10 and 12 by electrical connections 58 and 60. Controller 5 could be a primary and supervisory control system that is capable of at least shutting off one of the two multistage compressors 10 and 12, controlling the inlet guide vanes 11 and 13 and again, although not illustrated, also controlling a vent lines and recirculation loops. During normal operating conditions both the higher pressure compressed and purified air stream 46 and the lower pressure compressed and purified air stream 48 and therefore, the first compressed air stream 50 and the second compressed air stream are formed by the two multistage compressors 12 and 10 respectively. However, during turndown operating conditions when a lower flow rate for the oxygen product stream 54 is desired, the first compressed air stream 50 and the second compressed air stream 52 are formed by turning off compressor 10 and forming both such streams, at a lower flow rate, from multistage compressor 12. Under such operational conditions, the multistage compressor 12 can to a limited extent be turned down by use of its inlet guide vanes 11 to 13 to even provide lower air flow. Typically, control of the flow by the inlet guide vanes 11 and 13 allows the two multistage compressors 10 and 12 to be turned down to between 70 and 80 percent of capacity. In fact, the present invention as set forth in the appended claims is not meant to exclude operation of both of the two multistage compressors 10 and 12 at a reduced capacity with inlet guide vane control. However, below the level of between 70 and 80 percent of capacity, aerodynamic considerations come into play in which the compressor cannot be turned down without surging. In order to overcome this, vent and recirculation lines are provided to allow the output of the compressor to be further reduced. However, the venting or recirculation of the compressed air, while reducing the flow output of the compressor will not reduce the power consumption of the compressor. Thus, during turndown conditions of the plant, assuming the most ideal compressor in which power consumption is proportional to flow through the compressor, the power consumption will never be reduced below about 80 percent even when less than 80 percent of the flow is desired. In the present invention, however, by employing two multistage compressors, during turndown conditions one of the compressors is able to be turned off. This allows the compression system 2 to consume 50 percent of the power that it would be required to consume during normal operational conditions and with inlet guide vanes, the range of the compression system 2 will be from 40 to 100 percent with the power consumption being proportional to the flow rate at flow output of 40 percent, 50 percent and 80 percent.

The compression system 2 can be one of a series of compression systems employed in an envelope of air separation plants. In such case, a greater range of oxygen production can be obtained by either shutting down one of the plants or turning off one of the multistage compressors of a plant and etc.

With reference to FIG. 2, a process flow diagram of an embodiment of the main heat exchanger 62 and the distillation column system 64 contained in block 4 of FIG. 1 are illustrated. The first and second compressed air streams 50 and 52 are cooled within a main heat exchanger 62 that in practice would consists of a series of such heat exchangers linked in parallel. The first compressed air stream 52 is fully cooled in the main heat exchanger 62 to a temperature suitable for its rectification. In this regard, the term “fully cooled” as used herein and in the claims means cooled to a temperature at the cold end of the main heat exchanger 2. The first compressed air stream 52 is therefrom introduced into a higher pressure distillation column 66 of the distillation column system 64 that houses a first separation zone in which the air is rectified into a kettles liquid 68 and a nitrogen-rich vapor column overhead. Mass transfer contacting elements 70 and 72 are provided within distillation column 66 to contact liquid and vapor phases. The liquid phase becomes ever more rich in oxygen as it descends within distillation column 66 and the vapor phase becomes rich in nitrogen as it ascends within distillation column 66 to produce the kettles liquid 68 and the nitrogen-rich vapor, respectively. As well known in the art, mass transfer contacting elements 18 and 20 can be structured packing or trays or random packing or a combination of packing and trays.

A second separation zone is provided that is housed within a lower pressure distillation column 74 of the distillation column system 64 that is thermally linked to the first separation zone housed within the higher pressure distillation column 66 with the use of a condenser reboiler 76 that is illustrated as located in a sump 78 of the lower pressure distillation column 74 that forms the bottom region of the second separation zone. The condenser reboiler 76 could be located external to the lower pressure distillation column 74. A nitrogen-rich vapor stream 80 composed of the nitrogen-vapor column overhead produced in the higher pressure column 66 is introduced into the condenser reboiler 76 where it is condensed through indirect heat exchange with down coming liquid produced in the lower pressure column. All of such down coming liquid is contacted with the condenser reboiler 76 to partially vaporize such liquid and thereby to produce boil-up within the lower pressure distillation column 74. Residual liquid 82 that is not vaporized collects within the sump 78 as a crude oxygen liquid. The condensed nitrogen-rich vapor produces a nitrogen-rich liquid stream 84 to produce reflux for the columns. In this regard, a first reflux stream
composed of part of the nitrogen-rich liquid stream 84 refluxes the higher pressure column and a second reflux stream 88 is introduced into a subcooling unit 90, valve 92 and then introduced as reflux to the lower pressure column 74. The introduction of the second reflux stream 88 initiates the formation of a descending liquid phase and the boil-up produced by the condenser reboiler 76, in part, initiates an ascending liquid phase that are contacted by means of mass transfer contacting elements 94, 95 and 96 within the lower pressure column 74 that can be structured packing, random packing, trays or a combination of such elements. All of the down coming liquid is the liquid phase enriched in oxygen is discharged from the lowermost mass transfer contacting element 96 to the condenser reboiler 76. A kettle liquid stream 98, composed of the kettle liquid 68 is subcooled within subcooling unit 90 and is introduced into the lower pressure column 74 after valve expansion within expansion valve 99.

The third separation zone is providing by a stripping column 100 of the distillation column system 64 that contains mass transfer contacting elements 102 as such as described above. A crude oxygen liquid stream 104 that is composed of the crude oxygen liquid 82 is introduced into the stripping column 100 and is stripped to produce a nitrogen containing vapor that is returned to the sump 78 of the lower pressure distillation column 74 as a nitrogen containing vapor stream 106. The stripping column 100 is reboiled by the first compressed air stream 50 after having been fully cooled within the main heat exchanger 62 by introducing the first compressed air stream 50 into a reboiler 108 to produce a liquid air stream 110 that, as will be discussed, forms part of the intermediate reflux that is supplied to the higher pressure distillation column 66 and the lower pressure distillation column 74. The resulting residual liquid forms an oxygen-rich liquid 112 that can be taken as an oxygen-rich stream 114 in forming the oxygen product stream 54. In this regard, oxygen-rich stream 114 is vaporized in a vaporizer 116. Vaporizer 116 has a shell 118 and a heat exchanger 120 enclosed within the shell 118. The resulting vaporized oxygen-rich stream 122 is fully warmed within the main heat exchanger 62 to produce an oxygen product stream 54.

The first compressed air stream 50 is of a sufficiently high pressure and flow rate to provide boil-up within stripping column 100 that acts to increase the compositional difference between the liquid and vapor phases that would otherwise have been obtained at the pressure of the second compressed air stream 52. This increases the nitrogen content within the lower pressure column 74 and therefore decreases the temperature within such column such that the down coming liquid fed to the condenser reboiler 76 is able to condense the nitrogen-rich vapor of the nitrogen-rich vapor stream 80 at a lower pressure than the higher pressure of the first compressed air stream 50.

A second part 124 of the compressed and purified air stream 46 is introduced into a booster compressor 126 to produce another boosted pressure air stream 128 that, after removal of the heat of compression in an after cooler 130, is partially cooled in main heat exchanger 62 and expanded within a turboexpander 132 to produce an exhaust stream 134. As illustrated, the turboexpander 132 drives the booster compressor 126. Exhaust stream 134 is then introduced into the lower pressure column 74 to impart refrigeration into the apparatus 1.

A third part 136 of the higher pressure compressed and purified air stream 46 is divided into subsidiary streams 138 and 140 that, during normal operating conditions, are separately compressed in two booster compressors 142 and 144 and recombined into a further boosted pressure air stream 146. After removal of the heat of compression from further boosted pressure air stream 146 in an after cooler 148, the further boosted pressure air stream 146 is fully cooled and then condensed within vaporizer 116 to form a further liquid air stream 150. Further liquid air stream 150 is then subcooled within subcooling unit 90 along with liquid air stream 110 and then combined with liquid air stream 110 after valve expansion in an expansion valve 152. The combined liquid air stream is then divided into first and second intermediate reflux streams 154 and 156, respectively. First and second intermediate reflux streams 154 and 156 are then introduced as intermediate reflux into the lower pressure column 74 and the higher pressure column 66 after expansion within expansion valves 158 and 160.

During a shutdown mode of operation, controller 5 turns off booster compressor 142 such that the further boosted pressure air stream 146 is formed through compression of the third part 136 of the higher pressure compressed and purified air stream by booster compressor 144. For such control purposes, booster compressors 142 and 144 are connected to controller 5 by electrical conductors 162 and 164. As could be appreciated by those skilled in the art, booster compressors 142 and 144 could be incorporated into the two multistage compressors 10 and 12 as a high pressure final stage that would be connected to and located downstream of the of the final stages 22 and 24 of the two multistage compressors 10 and 12 illustrated in FIG. 1.

Subcooling duty for the subcooling unit 90 is provided by a nitrogen-rich vapor stream 166 that is removed from the lower pressure column 74. After partial warming within subcooling unit 166, the nitrogen-rich vapor stream 166 is fully warmed in the main heat exchanger 62 and discharged as the waste nitrogen stream 56.

With reference to FIG. 3, an alternative embodiment of the process flow diagram of an embodiment of the main heat exchanger 62 and the distillation column system 64 contained in block 4 of FIG. 1 is designated as 4'. This embodiment in most respects is the same as shown in FIG. 2 except that in place of the second reflux stream 86, a reflux stream 87 of lower purity is introduced into the lower pressure column 74. For such purposes, the higher pressure distillation column is slightly modified and is illustrated as distillation column 66 that differs from distillation column 66 by the replacement of mass transfer contacting elements 72 with mass transfer contacting elements 73 and 75. Although not illustrated a liquid collector would be positioned between such elements to permit the withdrawal of second reflux stream 87. An advantage of this is that a nitrogen liquid product stream 88 in place of the second reflux stream 88 shown in FIG. 2 can be withdrawn, subcooled within subcooling unit 90 and then used or sent to storage.

With reference to FIG. 4, an alternative embodiment of the process flow diagram of an embodiment of the main heat exchanger 62 and the distillation column system 64 contained in block 4 of FIG. 1 is designated as 4'. In this embodiment, the oxygen-rich liquid stream 114 is pumped by a pump 170 to produce a pressurized oxygen-rich liquid stream 122 that is heated in the main heat exchanger 62 to produce the oxygen product stream 54. If the pressurized oxygen-rich liquid stream 122 is supercritical, the resulting oxygen product stream 54 will be a supercritical fluid. In this regard, it is possible to bank the main heat exchanger 62 into
a lower pressure bank that would cool the streams previously discussed and a high pressure bank to heat the oxygen-rich liquid stream \(122^2\) through indirect heat exchange with further boosted pressure air stream \(146\). If, however, oxygen-rich liquid stream \(122^2\) is at a lower pressure, below supercritical, the resulting oxygen product stream \(54\) would be a high pressure vapor product.

[0041] With reference to FIG. 5, a further alternative embodiment of the process flow diagram of an embodiment of the main heat exchanger \(62\) and the distillation column system \(64\) contained in block 4 of FIG. 1 is designated as \(4^\text{th}\). In this embodiment, the distillation column system \(64\) is replaced by a distillation column system \(64^\text{th}\) having the second and third separation zones that in the preceding embodiments were housed in the lower pressure distillation column \(74\) and the stripping column \(100\) into a distillation column \(172\) having a second separation zone \(174\) and a third separation zone \(176\). The bottom region of the second separation zone is designated by column section \(78\). The oxygen rich liquid within the bottom regions of the second separation zone \(174\) would be distributed to the third separation zone \(176\) by a liquid distributor that, although not illustrated, would be conventional and include openings to allow the nitrogen containing vapor produced in the third separation zone \(176\) to the second separation zone \(174\). The operation of such embodiment is otherwise the same as that shown in FIG. 1.

[0042] Although the present invention has been described with reference to preferred embodiments, as will occur to those skilled in the art, numerous changes, additions and omissions can be made without departing from the spirit and scope of the present invention as set forth in the appended claims.

We claim:

1. A method of separating air to produce a gaseous oxygen product comprising:
   - separating the air in a cryogenic rectification process that is configured to produce an oxygen-rich stream by cryogenically rectifying the air within a distillation column system and warming the oxygen-rich stream, thereby to produce the gaseous oxygen product and that utilizes a first compressed air stream and a second compressed air stream having a lower pressure than the first compressed air stream;
   - producing the first compressed air stream and the second compressed air stream to feed the cryogenic rectification process by compressing the air in two multistage compressors linked together such that during a normal mode of operation, a high pressure air stream is produced from higher pressure stages of the two multistage compressors and a lower pressure air stream is produced from lower pressure intermediate stages of the two multistage compressors, removing heat of compression from the higher pressure air stream and the lower pressure air stream and purifying the lower pressure air stream and the higher pressure air stream to produce a higher pressure compressed and purified air stream and a lower pressure compressed and purified air stream and forming the higher pressure air stream from at least part of the higher pressure compressed and purified air stream and the lower pressure air stream from at least part of the lower pressure compressed and purified air stream; and
   - operating the cryogenic rectification process in a turn-down mode of operation by turning off one of the two multistage compressors and producing the higher pressure air stream and the lower pressure air stream from higher and lower pressure intermediate stages, respectively, of the other of the two multistage compressors, thereby decreasing air flow to the cryogenic rectification process and therefore, production of the oxygen-rich stream and the oxygen product.

2. The method of claim 1, wherein:
   - the first compressed air stream is formed from the lower pressure compressed and purified air stream and the second compressed air stream is formed from a first part of the higher pressure compressed and purified air stream;
   - a second part of the higher pressure compressed and purified air stream is further separately compressed in a booster compressor to produce a boosted pressure air stream;
   - the boosted pressure air stream partially cooled and then expanded to produce an exhaust stream; and
   - the exhaust stream is introduced into the distillation column system to impart refrigeration into the cryogenic rectification process.

3. The method of claim 2, wherein:
   - the air contained in the first compressed air stream is rectified in a first separation zone of a distillation column system to produce a kettle liquid and a nitrogen-rich vapor;
   - a kettle liquid stream composed of the kettle liquid is introduced into a second separation zone of the distillation column system for further refinement, the second separation zone operating at a lower operational pressure than the first separation zone;
   - down coming liquid entering a bottom region of the second separation zone is partly vaporized through indirect heat transfer with a nitrogen-rich vapor stream composed of the nitrogen-rich vapor produced in the first separation zone thereby condensing the nitrogen-rich vapor stream and forming reflux for the first separation zone and the second separation zone and a crude oxygen liquid from residual liquid not vaporized through the indirect heat exchange;
   - a crude oxygen liquid stream composed of the crude oxygen liquid is stripped in a third separation zone of the distillation column system operating at the lower operational pressure such that a nitrogen containing vapor and an oxygen-rich liquid are produced, the oxygen-rich liquid having a lower nitrogen content than the crude oxygen liquid;
   - a nitrogen containing vapor stream composed of the nitrogen containing vapor is introduced into the second separation zone;
   - the third separation zone is reboiled with the second compressed air stream to form a liquid air stream;
   - intermediate reflux streams, composed at least in part from the liquid air stream, are introduced into the first separation zone and the second separation zone; and
   - the oxygen-rich stream is withdrawn from the third separation zone and is composed of the oxygen-rich liquid.

4. The method of claim 3, wherein:
   - a third part of the higher pressure compressed and purified air stream is divided into two further subsidiary streams that during the normal mode of operation are separately compressed within two additional booster compressors and recombined to produce a further compressed third part of the compressed and purified air stream and during the turn-down mode of operation the third part of the
higher pressure compressed and purified air stream is further compressed within one of the two additional booster compressors to form the further compressed third part of the compressed and purified air stream with the other of the two additional booster compressors turned off;
the further compressed third part of the compressed and purified air stream is fully cooled;
the oxygen-rich stream is vaporized and warmed in part through indirect heat exchange with the further compressed third part of the compressed and purified air stream, thereby producing further liquid air; and
the intermediate reflux is introduced in the first separation zone and the second separation zone by subcooling a further liquid air stream composed of the further liquid air and a liquid air stream, composed of the liquid air produced in reboiling the third separation zone, through indirect heat exchange with a waste nitrogen stream produced in the second separation zone prior to the waste nitrogen stream being fully warmed, part of the further liquid air stream is valve expanded and combined with the liquid air stream to produce a first intermediate reflux stream which is further valve expanded and introduced into the second separation zone and introducing a second intermediate reflux stream that is introduced into the first separation zone;
the kettle liquid stream is introduced into the second separation zone by subcooling the kettle liquid stream through indirect heat exchange with the waste nitrogen stream prior to being fully warmed, valve expanding the kettle liquid stream and introducing the kettle liquid stream into the second separation zone; and
a first reflux stream composed of part of the condensed nitrogen-rich vapor refluxes the first separation zone and a second reflux stream composed of another part of the condensed nitrogen-rich vapor is subcooled through indirect heat exchange with the waste nitrogen stream, valve expanded and refluxes the second separation zone.
5. The method of claim 4, wherein the oxygen-rich stream is pumped prior to the oxygen-rich stream being vaporized and warmed through the indirect heat exchange with the further compressed third part of the compressed and purified air stream.
6. The method of claim 3 or claim 4 or claim 5, wherein:
the distillation column system has a higher pressure distillation column that houses the first separation zone, a lower pressure distillation column that houses the second separation zone and a side stripping column that houses the third separation zone; and
the kettle liquid stream is introduced into the second separation zone in the rectification column.
7. An apparatus for producing a gaseous oxygen product comprising:
an air separation plant configured to produce an oxygen-rich stream and utilizing a first compressed air stream and a second compressed air stream, the air separation plant having a main heat exchanger to cool the first compressed air stream and the second compressed air stream, a distillation column system connected to the main heat exchanger to rectify the air contained in the first compressed air stream and the second compressed air stream, thereby to produce the oxygen-rich stream and to return the oxygen-rich stream to the main heat exchanger such that the oxygen-rich stream is fully warmed to produce the gaseous oxygen product, a compression system connected to a purification system to produce the first compressed air stream and the second compressed air stream;
the compression system having two multistage compressors linked together such that during a normal mode of operation, a higher pressure air stream is produced from higher pressure stages of the two multistage compressors and a lower pressure air stream is produced from lower pressure intermediate stages of the two multistage compressors and after-coolers connected to the higher pressure stages and the lower pressure intermediate stages for removing heat of compression from the higher pressure air stream and the lower pressure air stream
the purification system configured to purify the lower pressure air stream and the higher pressure air stream to produce a higher pressure compressed and purified air stream and a lower pressure compressed and purified air stream;
the purification system connected to the main heat exchanger such that the first compressed air stream is formed from at least part of the higher pressure compressed and purified air stream and the second compressed air stream is formed from at least part of the lower pressure compressed and purified air stream; and
a control system for controlling the compression system such that the air separation plant is able to be selectively operated in the normal mode of operation and in a turn-down mode of operation in which one of the two multistage compressors is turned off and producing the higher pressure air stream and the lower pressure air stream from higher and lower pressure intermediate stages, respectively, of the other of the two multistage compressors, thereby decreasing air flow to the cryogenic rectification process and therefore, production of the oxygen-rich stream and the oxygen product.
8. The apparatus of claim 7, wherein:
the purification system is connected to the main heat exchanger such that the first compressed air stream is formed from the lower pressure compressed and purified air stream and the second compressed air stream is formed from a first part of the higher pressure compressed and purified air stream;
a booster compressor is connected to the purification system such that a second part of the higher pressure compressed and purified air stream is further compressed in the booster compressor to produce a boosted pressure air stream;
the booster compressor is connected to the main heat exchanger and the main heat exchanger is configured such that the boosted pressure air stream is partially cooled within the main heat exchanger;
a turbo-expander is positioned between the main heat exchanger and the distillation column system such that the boosted pressure air stream, after having been partially cooled, is expanded to produce an exhaust stream and the exhaust stream is introduced into the distillation column system to impart refrigeration into the cryogenic rectification process.
9. The apparatus of claim 8, wherein:
the distillation column system has a first separation zone, a second separation zone and a third separation zone, the first separation zone having a higher operational pressure than the second separation zone;
the first separation zone connected to the main heat exchanger so as to receive the first compressed air stream for rectification;

the second separation zone connected to the first separation zone such that a kettled liquid stream composed of kettle liquid produced in the first separation zone is introduced into the second separation zone for further refinement;

a condenser-reboiler is connected to the second separation zone and the first separation zone such that a nitrogen-rich vapor stream produced in the first separation zone indirectly exchanges heat to all down-coming liquid flowing towards a bottom region of the second separation zone, thereby condensing the nitrogen-rich vapor stream and partly vaporizing the down-coming liquid to produce boil-up in the second separation zone and a crude oxygen liquid collected in the bottom region of the second separation zone from down-coming liquid that is not vaporized;

the first separation zone and the second separation zone are in flow communication with the condenser reboiler such that reflux streams produced as a result of the condensing of the nitrogen-rich vapor stream are introduced into the first separation zone and the second separation zone;

the third separation zone is connected to a bottom region of the second separation zone to receive a crude oxygen liquid stream, composed of the crude oxygen liquid and to return a nitrogen containing vapor stream back to the bottom region of the second separation zone, the third separation zone configured to strip the crude oxygen liquid, thereby to produce the nitrogen containing vapor stream and an oxygen-rich stream having a lower nitrogen content than the crude oxygen liquid;

a reboiler is located in the third separation zone and in flow communication with the main heat exchanger receives the second compressed air stream, thereby to reboil the third separation zone and to produce liquid air;

the first separation zone and the third separation zone are in flow communication with the reboiler such that at least one intermediate reflux stream composed, at least in part, of the liquid air is introduced into at least one of the first separation zone and the second separation zone as intermediate reflux; and

the main heat exchanger is in flow communication with the third separation zone such that the oxygen-rich stream warms to form the oxygen product.

10. The method of claim 9, wherein:

two additional booster compressors are positioned between the purification system and the main heat exchanger such that during the normal mode of operation a third part of the higher pressure compressed and purified air stream is divided into two further subsidiary streams that are separately compressed and combined to form a further compressed third part of the higher pressure compressed and purified air stream;

the control system also controls the two additional booster compressors such that during the normal mode of operation both of the two additional booster compressors are in operation and in the turn-down mode of operation, the third part of the higher pressure compressed and purified air stream compressed within one of the two additional booster compressors to form the further compressed third part of the higher pressure compressed and purified air stream and the other of the two additional booster compressors is turned off;

the main heat exchanger is configured such that the further compressed third part of the higher pressure compressed and purified air stream fully cools within the main heat exchanger;

vaporizer is connected between the main heat exchanger and the third separation zone such that the oxygen-rich stream is removed from the third separation zone as a liquid and vaporized and warmed in part through indirect heat exchange with the further compressed third part of the compressed and purified air stream, thereby producing further liquid air;

at least one subcooling unit is connected between the reboiler, the second separation zone and the vaporizer such that a further liquid air stream composed of the further liquid air and a liquid air stream, composed of the liquid air, are subcooled through indirect heat exchange with a waste nitrogen stream produced in the second separation zone, the at least one subcooling unit also connected to the main heat exchanger such that the waste nitrogen stream fully warms within the main heat exchanger;

the second separation zone is connected to the at least one subcooling unit such that a part of the further liquid air stream combines with the liquid air stream to produce the intermediate reflux stream;

the first separation zone and the second separation zone are in flow communication with the at least one subcooling unit such that a first intermediate reflux stream composed of part of the intermediate reflux stream is introduced into the second separation zone and a second intermediate reflux stream composed of a further part of the intermediate reflux stream is introduced into the first separation zone;

the first separation zone is connected to the condenser reboiler such that a first of the reflux streams is introduced into the first separation zone;

the at least one subcooling unit is also connected to the higher pressure distillation column such that the kettled liquid stream subcohls within the at least one subcooling unit through indirect heat exchange with the waste nitrogen stream, a second of the reflux streams subcohls within the at least one subcooling unit through indirect heat exchange with the waste nitrogen stream;

the second separation zone is connected to the at least one subcooling unit such that the second separation zone is refluxed with the second of the reflux streams; and expansion valves are positioned between the at least one subcooling unit and the second separation zone such that the part of the further liquid air stream is expanded prior to combining with the liquid air stream and the first intermediate reflux stream is expanded prior to entering the second separation zone, the second of the reflux streams is expanded prior to entering the first separation zone and the kettled liquid stream is expanded before introduction into the second separation zone.

11. The method of claim 9 or claim 10, wherein:

the distillation column system has a higher pressure distillation column that houses the first separation zone, a lower pressure distillation column that houses the second separation zone and a side stripping column that houses the third separation zone; and

the bottom region of the second separation zone is a sump in the lower pressure distillation column that contains the condenser reboiler.