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(54) **Air separation method to produce gaseous product at a variable flow rate**

(57) A method of producing a gaseous product, for instance gaseous oxygen in accordance with a cyclical demand pattern having high and low periods of demand. During periods of high demand, liquid is vaporised against condensing air which is in turn stored. During low demand periods, product is accumulated and previously stored liquid air is introduced into the column. During both high and low periods of demand liquid product

is drawn to reduce the percentage variance in the required flow rate to the booster compressor used in producing the air to be liquefied. Preferably, during periods of high demand, a turbine used in generating refrigeration can be turned down to increase the amount of air available for condensation and with a reduction in production of liquid product.

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Description

[0001] The present invention relates to a method of separating air to produce a gaseous product to meet a varying demand for it.

[0002] There are various processes and apparatus that have been provided in the prior art to separate air and thereby produce gaseous products in accordance with a demand cycle. During a demand cycle, demand cyclically swings between periods of high and low demand. In accordance with such demand, more gaseous product is produced during the high demand period than during the low demand period. This type of production requirement is often required in industries having a cyclical demand for oxygen, such as in the production of steel.

[0003] The air is generally separated by being purified to remove impurities of low volatility, cooled to near its dew point, and separated in a double rectification column comprising a higher pressure rectification column, a lower pressure rectification column, and a condenser-reboiler placing the top of the higher pressure column in heat exchange relationship with the bottom of the lower pressure column.

[0004] During periods of high demand, liquid oxygen that has been previously produced during a low demand period and stored within a storage tank, is pressurised by being pumped and then fully vaporised within the main heat exchanger of the air separation plant against condensing flow of air that has been boosted in pressure to well above the operating pressure of the higher pressure column. The resultant condensed air stream is in part stored and in part introduced into the higher pressure distillation column. During the low demand period, the previously stored liquid air is supplied to the higher pressure distillation column.

[0005] A practical difficulty in effectuating a process such as been described above is that during periods of high demand, more air must be further compressed and therefore liquefied in order to vaporise the increase in the flow rate of product. Inlet flow to the booster compressor can vary by as much as 50%. Most known compressors are not able to accommodate such a variation of inlet flow without recirculating of the outlet flow. Thus, in order to accommodate a 50% of design flow rate, part of the outlet flow of the compressor must be recirculate back to the inlet. The compressor must be sized, however, to produce the requisite outlet flow. As a result, the booster compressor has an over capacity when flow rates are 50% and therefore, practically, a larger compressor is used than would theoretically be necessary. This is not efficient from standpoints of both equipment cost and electrical power usage.

[0006] As will be discussed, the present invention makes it possible to meet a demand cycle without excessive swings of air flow rate for further compression (typically in a booster-compressor) and thereby permits more efficient compressor utilisation.

[0007] According to the present invention there is provided a method of separating air to produce a first gaseous product, enriched in a component of the air in accordance with a demand cycle having high and low periods of demand, and a second liquid product said method comprising:

forming a first liquid stream by cryogenic rectification of a stream of air compressed to a first pressure, liquid stream being enriched in said component of the air;

during periods of low demand for the first gaseous product, storing liquid from said first liquid stream;

during periods of high demand for the first gaseous product, pressurising a first product stream withdrawn from the stored liquid product, vaporising the pressurised stream to produce said first gaseous product, and condensing or liquefying a first further compressed air stream passing in indirect heat exchange with the vaporising pressurised stream; and

also during at least the periods of low demand, withdrawing the second liquid product and producing refrigeration for the method by expanding a second further compressed air stream with performance of work.

[0008] The term "condensing" as used herein and in the claims encompasses not only a process in which a substance changes state from a vapour to a liquid, but also to processes in which a supercritical fluid is depressurised, after having been fully cooled, to produce a liquid. During at least the low period of demand, refrigeration is produced by expanding a second further compressed air stream with performance of work, thereby to refrigerate the low temperature rectification process and to permit production of the first and second liquid streams and also, producing a liquid product composed of the second liquid stream. As a result, the flow rate of the air to be further compressed during the low period of demand is greater than that that would otherwise have been required had the liquid product not been produced.

[0009] The advantage of the foregoing method is that increasing the air flow rate of the air to be further compressed, while resulting in an increase in compression requirements, actually reduces the required percentage increase between high and low demand periods that would otherwise have occurred. As will be discussed, production can be made to vary as can the amount of further compressed air that serves refrigeration purposes. In such a manner, the air that is

further compressed can serve in vaporizing the pressurized liquid product and thus air flow swings to the main air compressor can be further reduced. In fact, a process can be carried out in which the air flow rate to the booster compressor remains unchanged during periods of both high and low demand.

[0010] The method according to the invention will now be described by way of example with reference to the accompanying drawing which is a schematic flow diagram of an air separation plant.

[0011] With reference to the figure, air separation apparatus 1 in accordance with the present invention is illustrated that can be used to produce both gaseous nitrogen and gaseous oxygen products.

[0012] In accordance with a method of operation of air separation apparatus 1, air after having been filtered in a filter 10 is compressed by a main air compressor 12. The heat of compression is removed from the resultant compressed air by an after-cooler 14. The air is further purified by removal of impurities such as carbon dioxide and moisture by a known prepurification unit 16. The air is further compressed by a booster compressor 18 to form a further compressed air stream 20. Further compressed air stream 20 is introduced into a main heat exchanger 22 where it is cooled against other warming streams passing countercurrently through main heat exchanger 22. Although main heat exchanger 22 is illustrated as a single unit, in practice, the heat exchanger might be a heat exchanger complex of several heat exchangers.

[0013] Further compressed air stream 20 after having been partly cooled, that is cooled to a temperature that is less than the temperature at the warm end and greater than the temperature at the cold end of main heat exchanger 22, is divided into first and second further compressed air streams 24 and 26. First further compressed air stream 24 is cooled to a liquefaction temperature and second further compressed air stream 26 is turboexpanded within a turboexpander 28 to produce a refrigerant stream 30. Refrigerant stream 30 adds refrigeration to air separation apparatus 1 and helps in making a liquid product. In the illustrated embodiment, turboexpander 28 provides most of the refrigeration. It is possible, however, to conduct a method in accordance with the present invention by supplementing the refrigeration by liquid assist (i.e. the introduction of liquid nitrogen or liquid air from a separate source into the apparatus) as for instance during periods of high demand for product. In fact during such high periods of demand, all of the refrigeration might be supplied by liquid assist.

[0014] A compressed air stream 32 is formed by diversion of part of the prepurified air upstream of the booster compressor 18 to the main heat exchanger 22. Compressed air stream 32 is cooled to approximately its dew point and combined with refrigerant stream 30. The resultant stream is introduced into the bottom of an air separation unit 34.

[0015] Air separation unit 34 consists of a higher pressure column 36 and a lower pressure column 38. Higher and lower pressure columns 36 and 38 contain mass transfer elements, which can consist of trays or packing, either random or structured. Higher pressure column 36 functions to distil the incoming air to produce a nitrogen rich overhead fraction and a crude liquid oxygen bottom fraction. Higher pressure column 36 is refluxed by removing a nitrogen rich stream 40 from the overhead fraction and condensing such stream in a condenser reboiler 42 to produce a reflux stream 44. Reflux stream 44 is divided into two parts. One part 46 is used to reflux higher pressure column 36. The other part 48 is subcooled within the subcooling unit 50, expanded through an expansion valve 52 to the pressure of the lower pressure column 38, and then introduced as reflux into lower pressure column 38.

[0016] The crude liquid oxygen produced as the bottom fraction of higher pressure column 36 is extracted as a crude liquid oxygen stream 54 for further refinement in the lower pressure column 38. Crude liquid oxygen stream 54 is subcooled within subcooling unit 50 and expanded through an expansion valve 56 before introduction into lower pressure column 38 for further refinement. This further refinement produces an oxygen rich liquid bottom fraction within lower pressure column 38. The oxygen-rich liquid bottom fraction is boiled by condenser-reboiler 42 to produce boil up within lower pressure column 38. The oxygen-rich liquid fraction is the source of the oxygen product (s). High purity oxygen products, to wit: having a purity above 99% or relatively impure oxygen products, for instance, oxygen enriched air at 30% may be separated. Lower pressure column 38 also produces a gaseous nitrogen stream 58 which passes counter currently through subcooling unit 50 to subcool part 48 of reflux stream 44 and crude liquid oxygen stream 54 before fully warming within heat exchanger 22 and being discharged from the process.

[0017] Apparatus 1 is designed to function to produce a gaseous oxygen product at elevated pressure at greater output during periods of high demand than that required at periods of low demand.

[0018] In order to produce the liquid oxygen product a liquid oxygen stream 60 is extracted from the lower pressure column 38 and divided into first and second liquid streams 62 and 64. The first stream 62 is introduced into a liquid storage tank 66. The second liquid stream 64 is introduced via a valve 67 into liquid product tank 68 from which liquid oxygen product stream 70 can be extracted. A liquid oxygen stream 72 is taken from the tank 66 and is pressurised by operation of a pump 74. The pressurised liquid oxygen stream is vaporized within main heat exchanger 22 to produce the gaseous oxygen product at a chosen pressure. As is known in the art, in lieu of pump 74, a hydrostatic head can be utilized to pressurise the liquid provided that the pressure at which the gaseous oxygen product is required is not too high. Moreover, if desired a single liquid oxygen storage tank may replace the storage tanks 66 and 68 with both the streams 70 and 72 being taken therefrom.

[0019] During periods of low demand for the gaseous oxygen products all the air stream 24 that has been cooled in

the main heat exchanger 22 to its liquefaction temperature flows as stream 76 through expansion valve 85 and is introduced in liquid state (except for flash gas) into an intermediate liquid-vapour contact region of the higher pressure rectification column 36.

[0020] During periods of high demand, more liquid air is produced. The extra liquid air, as stream 78, is routed to a storage tank 80 and liquid air is accumulated therein. At the same time, because the demand for the gaseous oxygen product is high the flow rate of stream 72 exceeds that of stream 62, liquid oxygen within liquid oxygen product tank 66 is depleted. On the other hand, during periods of low demand, the amount of liquid oxygen within the liquid oxygen storage tank 66 is built up. Further, during these periods, liquid air previously accumulated in liquid air storage tank 80 is taken therefrom as an air stream 82 and is combined with the stream 76 of the condensed air by opening a valve 84. The combination of these two air streams takes place upstream of the expansion valve 85. In such manner liquid flow to the column is kept relatively constant during both high and low demand periods. As may be appreciated, liquid air could be produced in surplus amounts so as to be available as a liquid air product.

[0021] It is to be noted that in the present invention it is not essential to store liquid air. Thus, it is possible to design a cycle in accordance with the present invention in which during periods of high demand, all liquid air would be introduced into the rectification column for separation. A further point is that if the booster-compressor 18 has a supercritical outlet pressure the air stream 78 would be passed through an expansion valve (not shown) into the tank 80. The resultant vapour fraction (known as 'flash gas') produced by such expansion would be introduced into the rectification columns.

[0022] As stated above, it is not efficient to incorporate an operation in which booster compressor 18 is subjected to large swings in flow rates. In the subject invention, apparatus 1 is continually loaded by production of a liquid product stream 70 in addition to the gaseous product. As a consequence, there is always some refrigeration requirement that is supplied by the use of booster compressor 18 and therefore, the flow rate thereto will not vary to the same degree had no liquid been produced. During periods of high demand, for the gaseous oxygen product, the turboexpander 28 is turned down. In this regard, turboexpander 28 is provided with variable inlet vanes to control the flow thereto. The illustrated compressor 18 is provided with a similar arrangement. Turning down turboexpander 28 will cause an excess flow, that would otherwise have gone into turboexpander 28 to form the make-up of first further compressed air stream 24. Such operation provides more available air to be liquefied and therefore more liquid air for use in vaporising liquid oxygen product stream 72. Since, however, there will be less refrigeration, there will be less liquid produced and thus, valve 67 will be turned down so that more liquid oxygen will flow to liquid oxygen storage tank 66. As may be appreciated, the entire system may be adjusted so that booster compressor 18 sees no change in air flow and main air flow compressor 12 sees only a slight change in air flow.

[0023] Calculated examples are set forth in the following table of three liquid production schemes. Case 1 is a comparative known production method in which no liquid product is taken. Case 2 involves the production of a liquid product in the amount of 30 tons per day. Lastly, Case 3 involves an average liquid production of 30 tons per day. The liquid production in Case 3 is not however constant and varies.

TABLE

	CASE 1	CASE 2	CASE 3
	Low Demand	High Demand	Low Demand
Total Gaseous Oxygen Production (Tons/Day)	70	210	70
Stream 62 (Tons/Day)	140	140	140
Stream 64 (Tons/Day)	--	--	30
Booster Compressor 18 Flow Rate (Nm³/hr)	6049	11634	12621
Main Air Compressor 12 Flow Rate (Nm³/hr)	15335	20919	19212
Stream 60 (Tons/Day)	140	140	170
Stream 78 (Nm³/hr)	--	2792	--
Stream 82 (Nm³/hr)	2792	--	2792

In Case I there is a flow to booster compressor 18 varying (between high and low demand periods) by about 48%. In Case II where there is some liquid production in accordance with the present invention, the variance is reduced to about 31%. In case III the flow to booster compressor 18 is constant.

[0024] The present invention has applicability not only to pressurized oxygen production but also to production of pressurized nitrogen. In another modification, a liquid nitrogen product is produced instead of a liquid oxygen product. If desired, more than one turbo-expansion can be employed at more than one temperature. Again, if desired, an argon column can be provided for the production of argon. A still further point is that the liquid oxygen to be pumped (or any alternative product) could be stored in a pressurized state. This would allow the pump 74 to run at a constant nominal rate to conserve energy.

[0025] Although the present invention has been described with reference to preferred embodiment, as will occur to the skilled in the art, numerous changes, additions, and omissions may be made without departing from the spirit and scope of the present invention.

Claims

1. A method of separating air to produce a first gaseous product, enriched in a component of the air in accordance with a demand cycle having high and low periods of demand, and a second liquid product said method comprising:

forming a first liquid stream by cryogenic rectification of a stream of air, compressed to a first pressure, the first liquid stream being enriched in said component of the air;

during periods of low demand for the first gaseous product, from said first liquid stream;

during periods of high demand for the first gaseous product, pressurizing a first product stream withdrawn from the stored liquid product, vaporizing the pressurised stream to produce said first gaseous product, and condensing or liquefying a first further compressed air stream passing in indirect heat exchange with the vaporising pressurised stream; and

also during at least the periods of low demand, withdrawing the second liquid product and producing refrigeration for the method by expanding a second further compressed air stream with performance of work,

2. A method according to Claim 1, wherein the first gaseous product and the second liquid product are both withdrawn continuously and said second further compressed air streams expanded continuously.

3. A method according to Claim 2, wherein the second liquid product is withdrawn at a constant rate.

4. A method according to Claim 1 or Claim 2, further comprising during said high demand periods increasing the flow rate of said first further compressed air stream, decreasing the flow rate of said second further compressed air stream thereby to decrease the rate of generation of refrigeration and to decrease the rate of production of the second liquid product, the first flow rate of said further compressed air stream being sufficiently increased to allow for vaporisation of said product stream.

5. A method according to Claim 4, wherein said first flow rate is increased and said second flow rate is decreased so that said air flow rate of the air to be further compressed does not vary between high and low demand periods.

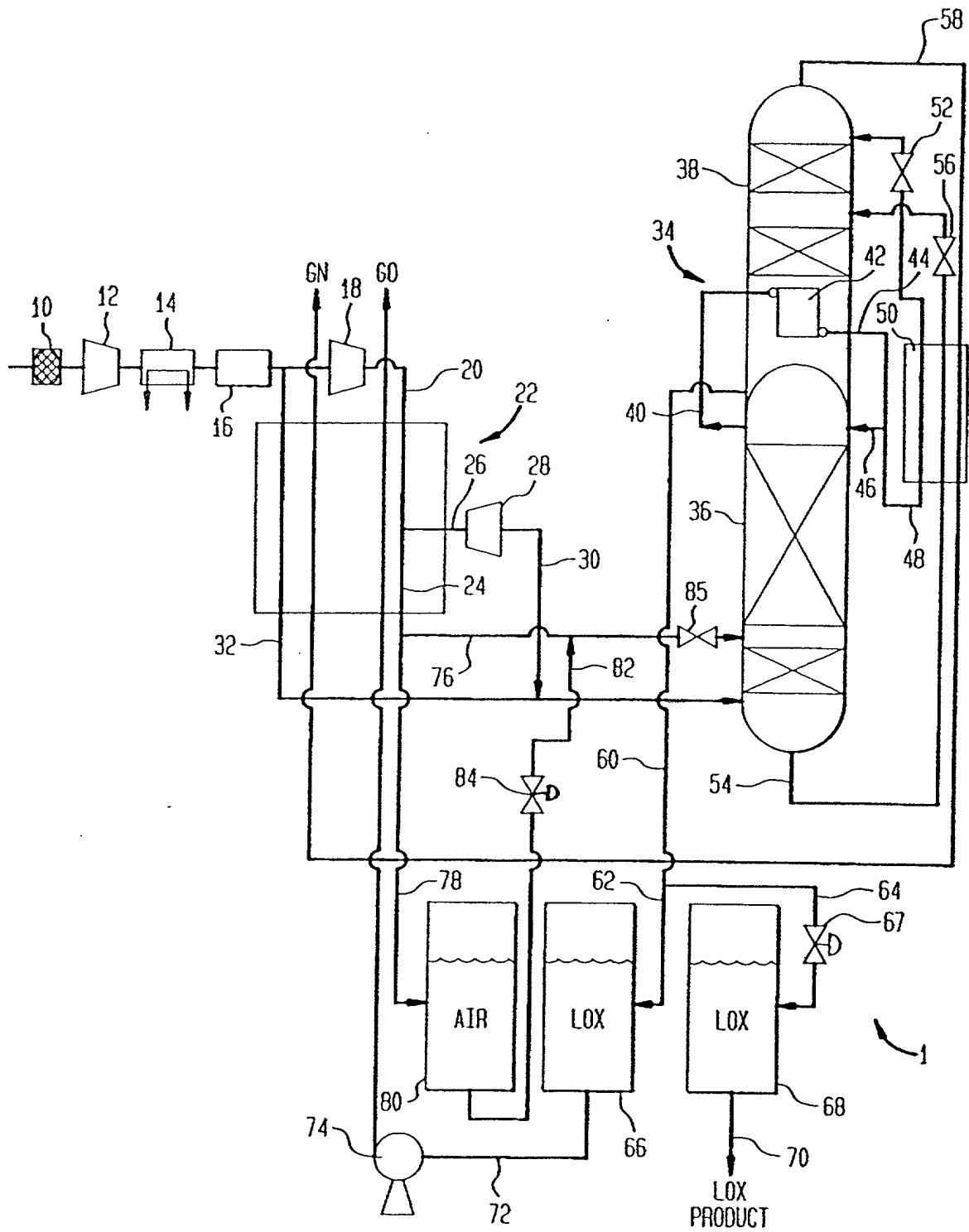
6. A method according to any one of the preceding claims, wherein said component comprises oxygen.

7. A method according to Claim 6, wherein said liquid stream is also enriched in said component.

8. A method according to any one of the preceding claims wherein:

during the period of low demand liquid air is introduced from storage into the cryogenic rectification process as part of the air to be separated; and during the periods of high demand, liquid air is taken from said condensed or liquefied first further compressed air stream.

9. A method according to any of the preceding claims, wherein the first and second further streams of air are both taken from the same booster-compressor which is operated with a constant flow rate of air therethrough.





European Patent
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EUROPEAN SEARCH REPORT

Application Number
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CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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