Dec. 4, 1962 L. D. POTTS 3,066,494

PROCESS OF AND APPARATUS FOR LOW-TEMPERATURE SEPARATION OF AIR

Filed May 26, 1958

3 Sheets-Sheet 1

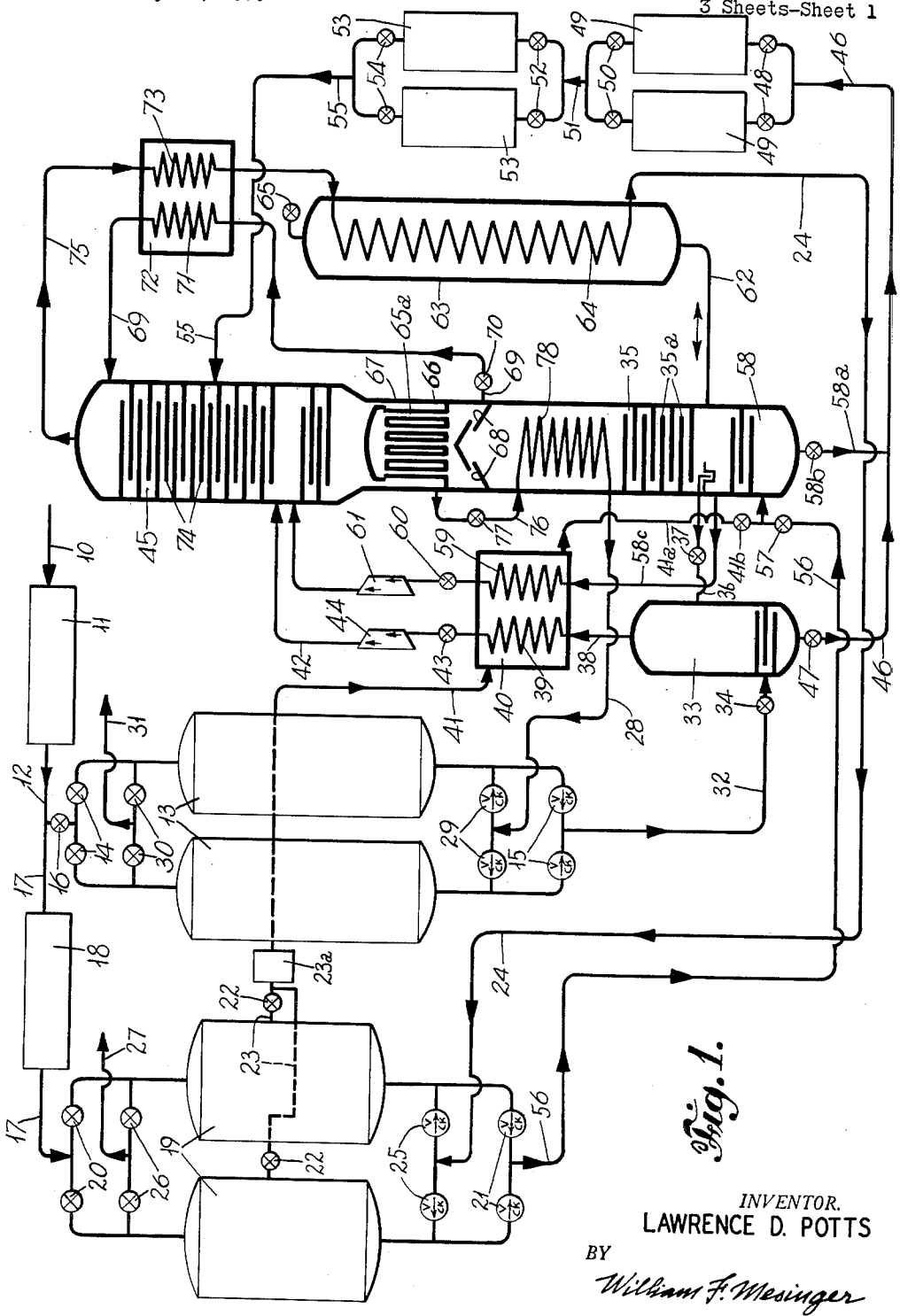

Fig. 1.

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Filed May 26, 1958 3 Sheets-Sheet 2

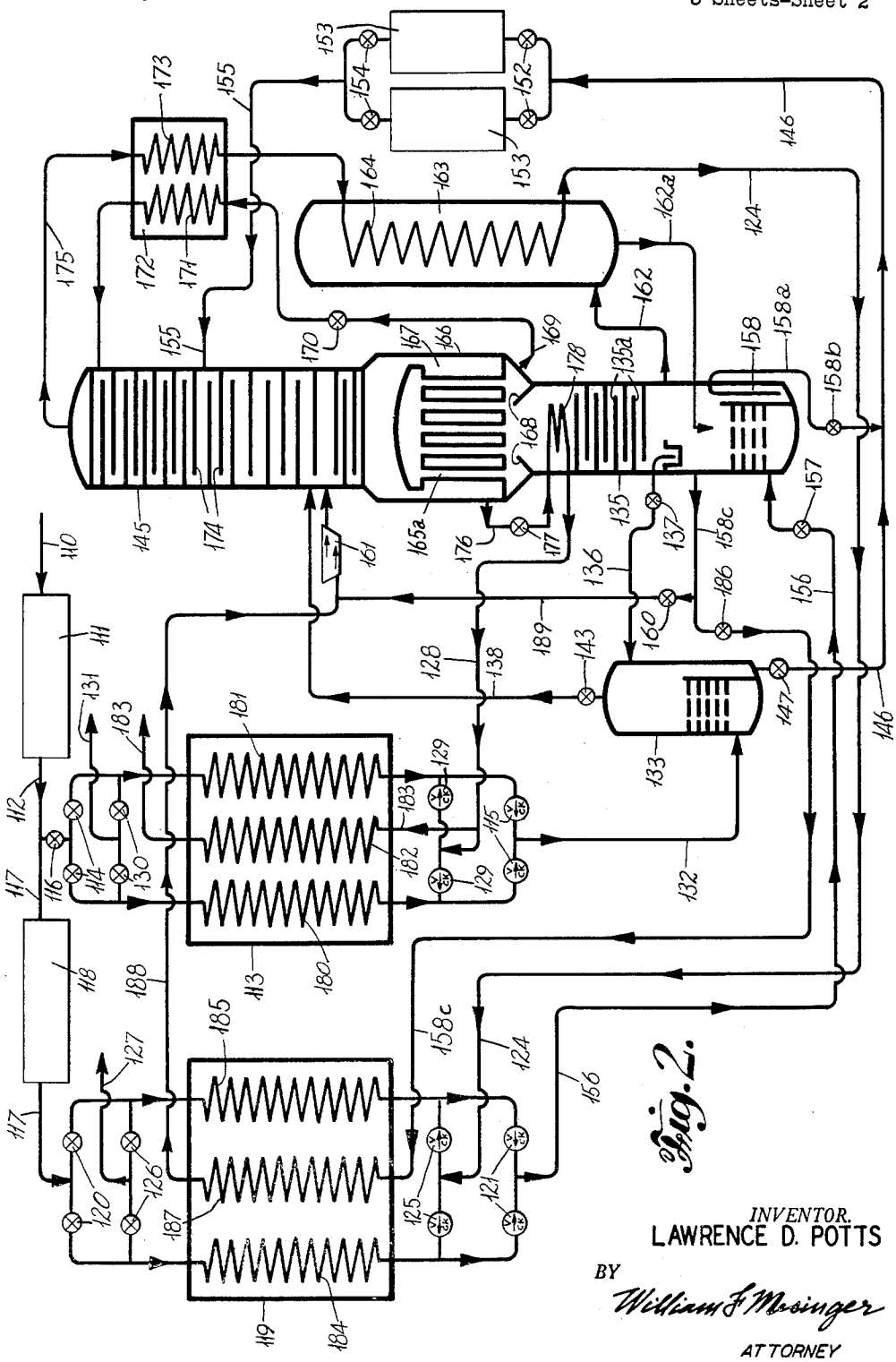

Fig. 2.

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Filed May 26, 1958 3 Sheets-Sheet 3

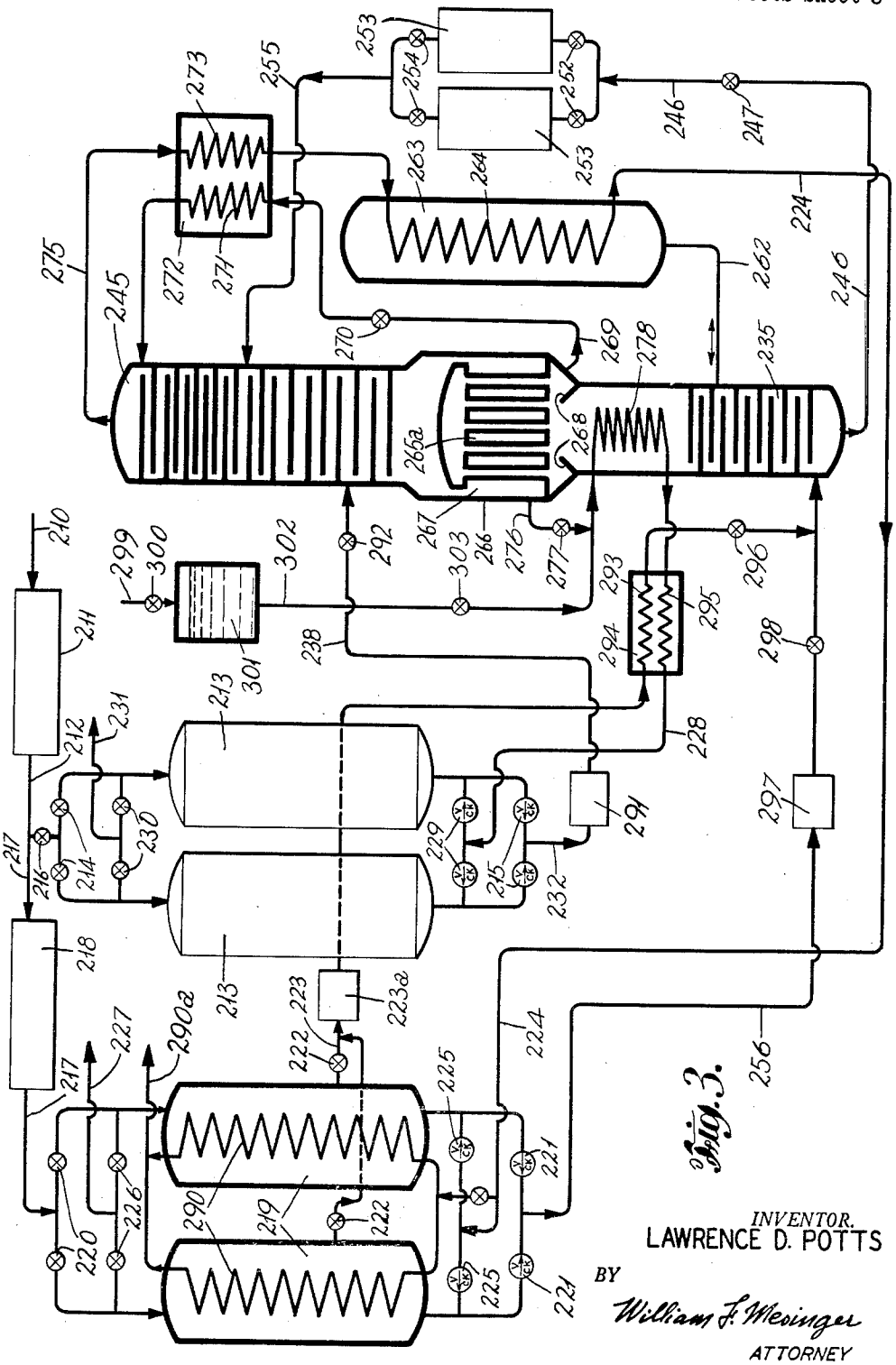

Fig. 3.

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United States Patent Office

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3,066,494

PROCESS OF AND APPARATUS FOR LOW-TEMPERATURE SEPARATION OF AIR

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Filed May 26, 1958, Ser. No. 737,687
16 Claims. (Cl. 62—25)

This invention relates to an improved process of and apparatus for the low-temperature separation of air to produce low-purity gaseous oxygen and gaseous nitrogen, and more particularly to improvements of such process and apparatus resulting in the simplification of the heat exchange equipment and reduction of the power costs.

In the well-known Linde-Fränkl system for producing low purity gaseous oxygen, all of the air is compressed to at least 75 p.s.i.g., and at least most of the air is cooled to about saturation temperature in heat exchangers of the regenerative or passage exchanging, self-cleaning type, and passed to the rectification column for separation therein. Unless externally supplied refrigeration is used, a minor part of the cold air is work expanded and passed to the lower pressure rectification stage, while the major part of the cold clean air is passed to the high pressure rectification stage. The inlet or head pressure of the incoming air is usually determined by the pressure differential required to operate the reboiler or main condenser separating the higher and lower pressure stages. Thus, the inlet air must be sufficiently compressed to provide transfer of heat from the condensing higher pressure nitrogen in the top of the high pressure stage or lower column to the boiling lower pressure liquid oxygen in the reboiler base of the lower pressure stage or upper column. One disadvantage of the aforedescribed Linde-Fränkl system is that all of the air is compressed to the pressure required by the reboiler for condensing nitrogen. However, when only a low purity oxygen product is required, a relatively large part of the inlet air stream may bypass the lower column separation. This means that in the prior art single-pressure systems, power is being wasted to compress a part of the inlet air to a higher pressure than is needed to satisfy both rectification and refrigeration requirements.

In order to overcome this limitation and also provide an efficient air separation system with sufficient flow unbalance to make the air cooling heat exchangers self-cleaning, the prior art has proposed various dual-pressure cycles in which air is usually compressed to two different pressures by separate compressors. For example, in a modified Linde-Fränkl system a minor air stream is compressed to high pressure, e.g. 2,000 p.s.i., cooled in a separate heat exchange system from that processing the main air stream, cleaned, and passed to the rectification column for separation along with the main air stream. The separately processed high pressure air may, for example, be cooled by an externally supplied refrigerant and/or a portion of the oxygen or nitrogen separation products. However, a dual pressure system utilizing a separate high pressure air stream does not solve the aforementioned problem because it provides a still higher refrigeration potential, which is not required by the cycle. Another significant drawback of this system is that a complicated heat exchange system is required which increases investment and operating costs. For example, if the product nitrogen effluent is divided and used to cool both the major and minor air streams, the air-nitrogen heat exchange must be split into two exchange systems, whereas in the basic Linde-Fränkl system, the air and nitrogen are heat exchanged in a single heat exchange system.

Another disadvantage of certain previously proposed

air separation systems for producing low purity gaseous oxygen is the relatively inefficient heat exchange across the main condenser, between the condensing nitrogen gas and boiling oxygen liquid. In one such reboiler, gaseous nitrogen reaching the top of the lower column rises into a series of tubes which on the upper column lower pressure side, are surrounded by a liquid oxygen bath. As the gaseous nitrogen is cooled to the saturation point, it condenses and falls back through the tubes in countercurrent direction to the warmer rising nitrogen gas, into the lower column. Since the descending liquid nitrogen tends to run down and coat the tube walls, heat exchange contact between the rising nitrogen and liquid oxygen bath is relatively poor. Also, boiling oxygen of relatively high purity must condense substantially pure nitrogen which necessitates a relatively large pressure differential since at atmospheric pressure, nitrogen boils at —196° C. and pure oxygen boils at —183° C. Since, as previously discussed, in the prior art systems the air head pressure is determined primarily by the main condenser heat exchange requirements, inefficient heat exchange necessitates a high air inlet pressure which results in excessive power costs. The prior art has partially alleviated this problem by concurrently evaporating the liquid oxygen, but despite this improvement the condenser-reboiler has continued to impose higher total work of compression than demanded by the system's refrigeration balance.

Principal objects of the present invention are to provide a process and apparatus for the production of low purity gaseous oxygen by air separation in a multi-pressure double column cycle in which the power consumption is no higher than that required by the refrigeration balance, and in which the incoming air-outgoing oxygen and nitrogen air separation product heat exchange system is simplified.

These and other objects and advantages of this invention will be apparent from the following description and accompanying drawings in which:

FIG. 1 shows a flow diagram of a system for the separation of air according to the present invention in which both higher and low pressure air are work expanded;

FIG. 2 is a flow diagram of a system similar to that of FIG. 1 but modified so that only higher pressure air is work expanded; and

FIG. 3 is a flow diagram of still another system similar to that of FIGS. 1 and 2, but modified so that no work-expansion is required.

According to the present invention, a major air stream is compressed to a higher pressure approximating the operating pressure of the higher pressure rectification stage, and a minor air stream is compressed to a low pressure intermediate the operating pressures of the higher and lower pressure rectification stages. The major and minor air streams are cooled to temperatures close to their respective condensation temperatures by heat exchange with the nitrogen and oxygen products, respectively, of the rectification, the major and minor air stream volumes being apportioned or matched for such heat exchanges with the volumes of at least most of the nitrogen and oxygen products, respectively. In the description and the claims, heat exchange with the nitrogen and oxygen products refers to both recuperative heat exchange between the fluids in thermally associated separate passageways, and regenerative heat exchange through an intermediate refrigeration storage means such as regenerative packing. Next, the cold minor air stream is passed to the lower pressure rectification stage for separation therein, and at least most of the cold major air stream is passed to the higher pressure stage for partial rectification and condensation therein to form at least a nitrogen-rich liquid and an oxygen-

enriched liquid. The liquids are withdrawn from the lower column, throttled to the lower pressure of the upper column, and passed to such column for separation therein along with the minor air stream to provide said nitrogen and oxygen products.

The volume of product gas to be withdrawn through the smaller set of heat exchangers, e.g. oxygen regenerators, determines how much air should be passed as the minor air stream to the upper column. Also, a relatively larger proportion of the air processed as the minor air stream and passed to the upper column provides a relatively lower oxygen product purity. This is because such air bypasses the lower column rectification. Usually at least 20% of the total inlet air must be directed to the upper column as the low pressure minor air stream since this minimum amount is required for heat exchange against the total oxygen product. The process of the present invention is suitable for production of gaseous oxygen up to about 90% purity.

The minor air stream is preferably provided at a sufficiently high pressure between the operating pressures of the two rectification stages so that it may be work expanded to supply the cycle's entire low temperature refrigeration requirements. This is advantageous because it minimizes the quantity of air processed directly in the lower pressure stage, and consequently provides high rectification efficiency. If the minor low pressure air stream is not work expanded, then a portion of the major higher pressure air stream must be work expanded, and the lower pressure rectification stage must then process the entire minor air stream, e.g. 20% of the inlet air, plus the work expanded fraction, e.g. 10% of the inlet air. This is usually more air than can be processed by the lower pressure stage without decreasing the oxygen product purity. Therefore, when product purity requirements tend to limit the amount of air that can be separated efficiently in the lower pressure rectification stage, the minor air stream is preferably work expanded, and its pressure adjusted to be no higher than needed for the refrigeration balance. When lower oxygen product purity requirements permit considerably more air to be processed in the lower pressure stage, the minor air stream is preferably provided at only sufficient pressure to drive it into such stage, and a portion of the major higher pressure air stream is work expanded for refrigeration. However, even in the latter case, the volume of the minor air stream remains matched with the product volumes in the oxygen heat exchangers. Thus, the total work of compression will always be adjustable to suit the refrigeration requirements rather than being rigidly fixed at a higher level by temperature differences in the main condenser.

In one embodiment, liquid oxygen from the upper column is cocurrently evaporated by heat exchange with, and simultaneously condenses gas in the lower column so as to form reflux liquid for such column. The main condenser also provides reflux liquid for the lower column in the conventional manner, but the highly efficient cocurrent evaporation heat exchange step provides a substantial portion of the required reflux liquid and permits a relatively lower air head pressure with accompanying power savings. The term "cocurrent evaporation" as used herein refers to the vaporization of a liquefied gas mixture wherein the vapors flow cocurrently with the liquid, as described in U.S. Patent 1,963,840 to M. Fränkl.

The present air separation system also provides considerable flexibility of operation, in that the cycle's refrigeration requirements may be fulfilled by a number of methods, depending on the oxygen and/or nitrogen product purities. For example, either or both the cooled and cleaned major and minor air streams may be expanded to the lower pressure of the upper column with the production of external work, as previously discussed.

Referring now to the drawings and particularly to

FIG. 1, air entering the system through conduit **10** is compressed in first compressor **11** to a low pressure of less than about 44 p.s.i.g, e.g. 20 p.s.i.g., and the heat of compression may be removed by, for example, a water-cooled cooler (not shown). The low pressure air is discharged into conduit **12**, and a minor part of such air is directed as a minor air stream through control valve **16** to the warm end of an alternately reversed regenerator pair **13** for cooling to substantially condensation temperature at such low pressure. The minor air stream enters the regenerators through reversing valves **14** and emerges through check valves **15** at the cold end. The regenerators **13** operate in the well-known Fränkl manner, and are cooled and cleaned by outflowing product oxygen gas from the rectification column.

Returning now to the low pressure air stream in conduit **12**, the major part of this stream which is not passed to the oxygen regenerator pair **13** is conducted through conduit **17** to second compressor **18** for compression to a higher pressure below about 85 p.s.i.g., e.g. 41 p.s.i.g. The higher pressure air stream is discharged into conduit **17**, and the heat of compression may be removed by, for example, a water-cooled cooler (not shown). This major air stream is then directed to the warm ends of an alternately reversed second regenerator pair **19** for cooling to substantially condensation temperature at the higher pressure. The major air stream enters the regenerators through reversing valves **20** and emerges through check valves **21** at the cold ends. These regenerators **19** also operate in the well-known manner described in U.S. Patent 1,890,646 to M. Fränkl, and are cooled and cleaned by outflowing nitrogen product gas also from the column. A small fraction, e.g, 10%, of the major air stream is diverted from the nitrogen regenerator pair **19** at an intermediate temperature level, e.g. —110° C., so as to unbalance the regenerators. As used herein, the term "unbalance" refers to the adjustment of temperature and flow conditions within the inlet air cooling heat exchangers so that all of the air impurities deposited within the heat exchangers by the inlet air are swept out by the outgoing cold purge gas. The diverted or "side-bleed" air is passed through control valves **22** and conduits **23** to adsorption trap **23***a*, for removal of the carbon dioxide impurity therein by gas phase adsorption on suitable material, such as silica gel. The cleaned side-bleed air is then processed in a manner to be described subsequently. The minor air stream and that portion of the major air stream which passes through the entire length of the regenerators are cooled well below the freezing points of the moisture and carbon dioxide impurities, so that the moisture and a substantial part of the carbon dioxide content of the inlet air are deposited therein. These impurities deposited from the major air stream are reevaporated and carried out of the regenerators **19** by the nitrogen effluent passing from conduit **24** through check valves **25** into the nitrogen regenerators **19** and out through warm end reversing valves **26** in conduit **27**. The impurity-containing warmed nitrogen effluent may be withdrawn to consuming means or discarded to the atmosphere. Likewise, the impurities from the minor air stream are carried out of the regenerators **13** by the oxygen product gas passing from conduit **28** through check valves **29** into the oxygen regenerators **13** and out through warm end reversing valves **30** in conduit **31**. The oxygen product of, for example 65% purity, may be withdrawn to consuming means. It is to be understood that if chemical cleanup means were employed to remove impurities from the inlet air upstream of the regenerators, at least some of the low-temperature impurity removal components would not be required.

The partially cleaned low pressure air is discharged through check valves **15** into conduit **32**, and passed into the base of low pressure scrubber **33** through control valve **34**. In this vessel the remaining carbon dioxide is transferred to the liquid by bubbling the cold low pressure air

through such liquid or through any suitable gas and liquid contact means to obtain the scrubbing action. Scrubber liquid is provided by throttling higher pressure, cleaned liquid air from the lower column 35 through conduit 36 and control valve 37 therein, into the scrubber 34. The unliquefied but cleaned low pressure air emerges through conduit 38 into passageway 39 of a countercurrent heat exchanger 40 where it is slightly warmed by heat exchange with the aforementioned side-bleed air entering exchanger 40 through conduit 41. The side-bleed air leaves exchanger 40 through conduit 41*a* and control valve 41*b* therein for juncture with the cold partially cleaned major air stream, to be described later in more detail. The slightly warmed or preheated low pressure air is discharged through conduit 42 and control valve 43 therein, and expanded with the production of external work through expansion turbine 44. It is to be noted that the low pressure air was slightly warmed prior to expansion to avoid condensation within the turbine 44 which could cause erosion of the turbine blades. The work expanded air in conduit 42 is passed to the upper column, lower pressure rectification stage 45 for separation therein.

Returning to the low pressure scrubber 33, the impurity-containing scrubber liquid is passed in conduit 46 through throttling valve 47 and filter inlet valves 48 into one or the other of a pair of the filters 49 for removal of the solid carbon dioxide impurities. These filters are provided in duplicate and piped in parallel for alternate operation so that when one filter becomes loaded with carbon dioxide, the liquid may be diverted to the other filter having previously been purged by means not illustrated. The filtered liquid emerges through filter discharge valves 50 into conduit 51, and passes through absorbent trap inlet valves 52 into one or the other of a pair of the adsorbent traps 53 for removal of soluble impurities by a suitable adsorbent such as silica gel. The cleaned scrubber liquid emerges through adsorbent trap discharge valves 54 into conduit 55, and enters the upper column operating at approximately 5 p.s.i.g.

The partially cleaned higher pressure major air stream discharged from nitrogen regenerator pair 19 through check valves 21 is conducted through conduit 56 and control valve 57 for juncture with the cooled side-bleed air in conduit 41*a* and passage to the base of a higher pressure scrubber 58 which is built into and communicates with the higher pressure, lower column 35. This unit operates in the same general manner as the low pressure scrubber 34 in that the higher pressure air bubbles through the descending reflux liquid which drains from the base of the lower column. The impurity-containing scrubber liquid is drawn from the base of higher pressure scrubber 58 through conduit 58*a* and throttling valve 58*b* therein to conduit 46 for passage along with the low pressure scrubber liquid to impurity-removing means, as previously described. The cleaned higher pressure air emerging from the scrubbing section 58 rises into the lower column 35 for separation by well-known means, for example rectification trays 35*a*.

As an alternate or supplement to the low pressure turbine 44, a small part of the lower column gas may be diverted through conduit 58*c* for preheating in passageway 59 of heat exchanger 40 by the side-bleed air. The slightly warmed diverted lower column gas is then passed through control valve 60 to turbine 61 for expansion therein with the production of external work. This work expanded stream is also passed to the upper column 45 at an intermediate point of such column for separation therein. Alternatively, the turbines could be staged so that the exhaust from high pressure turbine 61 is passed to the suction side of the low pressure turbine 44 for expansion therethrough along with the low pressure scrubbed air in conduit 42.

Another small part of the lower column gas is diverted through line 62 to heat exchanger 63 where the gas is liquefied by heat exchange with the upper column nitrogen effluent in passageway 64. Vent valve 65 is provided at the top of heat exchanger 63 to purge non-condensible gases from the system. The lower column gas liquefied in the exchanger drains back into the lower column 35 through conduit 62, thus providing additional scrubber liquid.

A portion of the lower column reflux liquid is produced in the conventional manner, by condensation of nitrogen-rich gas on the lower column side 65*a* of main condenser 66 against boiling liquid oxygen on the upper column side 67 of such condenser. At least most of the so condensed nitrogen-rich liquid is collected on shelf 68, and the remaining portion descends through the lower column as reflux liquid for the rising gas. The shelf liquid is drawn off through conduit 69, throttled through valve 70 from about 37 p.s.i.g. to about 5 p.s.i.g. and directed to passageway 71 in heat exchanger 72 where it is subcooled by the nitrogen effluent in passageway 73. The subcooled shelf transfer liquid in conduit 69 enters the top of upper column 45 as reflux liquid. The upper column 45 in general operates in the conventional manner, the incoming work-expanded air and reboiler vapor rising through trays 74 for rectification against the downflowing reflux liquid. The resulting nitrogen effluent at the top of upper column 45 is drawn off through conduit 75, and is superheated in passageway 73 of heat exchanger 72. The superheated nitrogen effluent is further warmed in heat exchanger 63 by the condensing lower column gas, and then passed through conduit 24 to the nitrogen regenerator 19 for processing as previously described.

The liquid oxygen accumulating in the lower column side 67 of the main condenser 66 is partially evaporated by heat exchange with the condensing nitrogen gas, so as to provide sufficient vapor to operate the upper column 45. When the required oxygen product purity is sufficiently low, e.g. below 85%, cocurrent evaporatoin of such product becomes attractive. In this event, instead of additionally transferring sufficient heat across the main condenser 66 to provide oxygen product gas for withdrawal from the upper column, liquid oxygen product is drawn off from the main condenser 66 through conduit 76 with control valve 77 therein, and cocurrently evaporated in coils 78 in the lower column 69 by heat exchange with the rising lower column gas, thereby allowing the lower column pressure to be reduced as will be explained hereinafter. The evaporated oxygen product emerging from soils 78 is passed through conduit 28 to the oxygen regenerator pair 13, for further processing as previously described. Thus, instead of transferring all of the necessary heat to the oxygen-rich liquid across the main condenser in a relatively inefficient manner, a substantial part of this heat is transferred with minimum irreversibility. A closer approach to a reversible process is obtained because the descending cocurrently evaporating liquid in coils 78 is not high purity oxgyen and at first more nitrogen preferentially boils off than oxygen. Thus, its boiling temperature is lowest at the top of the coils and the composition of the remaining liquid increases in oxygen so that the boiling temperature increases downwardly and is highest at the lowest portions of the coils 78. The ascending lower column vapor on the outside of the coils gradually becomes richer in nitrogen so that its condensing temperature is highest at the lower end of the coils 78 and lowest at the upper end of the coils. The net effect is a tendency towards a constant temperature difference between the evaporating oxygen-rich liquid and the condensing lower column vapor over the length of the coils, which results in efficient heat transfer and relatively low pressures. This type of heat exchange may be contrasted with the customary main condensers wherein all the heat must be transferred at a constant temperature level and which require a higher pressure difference since boiling oxygen-rich liquid of highest purity must condense substantially

pure nitrogen. The lower pressure difference permits a lower head pressure and consequently a power saving.

As previously discussed, instead of work expanding the low pressure minor air stream, a relatively small part of the higher pressure major air stream may be work expanded into the upper column. In such a system, the only pressure required for the minor stream may be that necessary to pass the low pressure air into the upper column for separation. The aforedescribed system is practical for use in relatively large air separation plants where the ratio of heat leak to air volume is low and for low purity oxygen plants which can accommodate relatively large quantities of air in the upper column.

Referring now to the embodiment illustrated in FIG. 2, the features which are similar to those shown in FIG. 1 are designated by similar reference numerals. The apparatus differs in certain particulars in that passage exchanging-reversing heat exchangers 113 and 119 are used instead of regenerators for cooling and partially cleaning the incoming air. Another alternate difference is that a part of the oxygen product gas from the rectification column is passed through the reversing heat exchanger 113 without contamination by the previously deposited air impurities, thus providing an oxygen product gas fraction free of air impurities. A third distinction from FIG. 1 is that only part of the higher pressure major air stream is work expanded, and the cleaned low pressure minor air stream is passed directly to the upper column without work expansion.

The minor air stream enters reversing heat exchanger 113 through one of reversing passageways 130 and 131, and is cooled by product oxygen flowing countercurrently in the other reversing passageway, and non-reversing passageway 182. The latter air impurity-free stream is discharged through conduit 183 for further processing as desired. The product oxygen stream entering non-reversing passageway 182 is provided by diverting a portion of the cocurrently evaporated gas from conduit 128 to conduit 183. The major air stream enters reversing heat exchanger 119 through reversing passageway 184 or 185, and is cooled by product nitrogen flowing countercurrently in the other reversing passageway and a cleaned cold portion of the major air stream also flowing countercurrently in non-reversing passageway 187. The latter stream is obtained by withdrawing a part of the cleaned higher pressure air from the base of the lower column 135 through conduit 158c, and a portion of such stream is passed through flow regulating valve 186 therein to non-reversing passageway 187. The warmed clean higher pressure air emerging from non-reversing passageway 187 is directed through conduit 188 to a juncture with cold, clean higher pressure air diverted from conduit 158c through conduit 189 with control valve 160 therein. The cold and warmed higher pressure air stream flows are proportioned so that the mixture is of suitable temperature, e.g. −169° C., and quantity for work expansion in turbine 161 to provide the required amount of refrigeration for the cycle.

If a relatively high oxygen product purity is required, all of the low pressure minor air stream should be work expanded, and all of the higher pressure major air stream should be separated in the lower column. This will permit the pressure of the minor air stream to be no higher than required by the refrigeration balance, and will minimize the quantity of air passed directly to the upper column. FIG. 3 illustrates another embodiment of the present invention in which neither the higher nor low pressure air stream is work expanded, but instead the cycle's refrigeration requirments are met by supplying liquid oxygen from an external source for cocurrent evaporation along with part of the liquid oxygen from the main condenser. Also, instead of removing residual impurities from the cold air streams by liquid scrubbing, such streams are cleaned by gas phase adsorption of the impurities therefrom. Another distinctive feature of FIG. 3 is that a portion of the product nitrogen may be recovered from the nitrogen regenerator pair 219 without contamination with the air impurities by passage through embedded coils 290.

Referring now more specifically to FIG. 3, the low pressure minor air stream is discharged from the oxygen regenerator pair 213 into conduit 232 and passed to adsorption trap 291 for removal of residual air impurities. The cleaned low pressure air is then passed through regulating valve 292 to upper column 245 for separation therein. The higher pressure major air stream is cooled in the nitrogen regenerator pair 219 by the refrigeration previously stored in the packing by the nitrogen purge gas, and by the nitrogen product gas passing through coils 290 embedded in the regenerators. The latter is discharged from the coils 290 into conduit 290a as a warm impurity-free product gas. The cleaned side-bleed air in conduit 223 is further cooled in passageway 293 of heat exchanger 294 by the oxygen product gas in passageway 295, and passed to the lower column 235 through control valve 296 for partial condensation and rectification therein. The partially cleaned cold major air stream is discharged from the nitrogen regenerator pair 219 into conduit 256 and passed through adsorption trap 297 for final cleanup, and directed through control valve 298 prior to entering lower column 235.

Refrigeration is provided by an external source of liquid oxygen connected to conduit 299 and control valve 300 therein, leading to storage tank 301. Liquid oxygen is drained therefrom through withdrawal conduit 302 and control valve 303 to a juncture with main condenser liquid oxygen in conduit 276. The combined stream is cocurrently evaporated in coils 278 and conducted to passageway 295 of heat exchanger 294 where the oxygen gas serves to cool the cleaned side-bleed air. Alternatively the liquid oxygen from storage tank 301 could be fed directly into the main condenser 266. The product oxygen gas is then passed to the oxygen regenerator pair 213 for further processing in the conventional manner. In order to take full advantage of the cocurrent evaporator, the externally supplied liquid oxygen is preferably of about the same purity as the main condenser liquid.

It can be seen from the foregoing description that the present invention provides a system for the production of low purity gaseous oxygen in which the power consumption is no higher than that required by the refrigeration balance since the air is processed in two parts, a higher pressure major stream and a low pressure minor stream, the total work of compressing the streams being adjustable to a minimum power requirement. The invention also facilitates cooling the two air streams to a simplified heat exchange system, since the major air stream is cooled by product nitrogen and the minor air stream is cooled by product oxygen.

It will be noted that in the specifically described and illustrated embodiments of the invention, the entire oxygen product is warmed in one set of heat exchange units and the total nitrogen product is warmed in another set. It is to be understood, however, that a portion of the oxygen product could be warmed in a non-reversing passage in the nitrogen exchangers or conversely a portion of the nitrogen product may be warmed in a non-reversing passage of the oxygen exchangers, the two sets of heat transfer units being identified by their respective reversing product flows. The important factor is that the major and minor air quantities should be matched with the volumes of at least most of the nitrogen and oxygen products, respectively.

Although preferred embodiments of the invention have been described in detail, it is contemplated that modifications of the process and apparatus may be made and that some features may be employed without others, all within the spirit and scope of the invention as set forth in the specification and claims. The principles of the invention

may also be applied to the separation of low-boiling gas mixtures similar to air.

What is claimed is:

1. A process for the separation of a gas mixture by low temperature rectification in a multi-pressure double column cycle including the steps of compressing a major gas mixture stream to a higher pressure approximating that of the higher pressure rectification stage; compressing a minor gas mixture stream to a low pressure intermediate the pressures of the higher and lower pressure rectification stages; separately cooling said major and minor gas mixture streams to temperatures close to their respective condensation temperatures by heat exchange with at least most of the lower-boiling and higher-boiling products, respectively, of the rectification, the major and minor gas mixture stream volumes being apportioned for such heat exchanges with the volumes of at least most of the lower and higher boiling products, respectively; passing the cold minor gas mixture stream to the lower pressure rectification stage for separation therein; passing at least most of the cold major gas mixture stream to the higher pressure rectification stage for partial rectification and condensation therein to form at least a lower boiling constituent rich liquid and a higher boiling constituent enriched liquid; throttling such liquids to a lower pressure and passing the liquids to said lower pressure rectification stage for separation therein along with the minor gas mixture stream to provide said lower-boiling and higher-boiling products.

2. A process for the separation of air by low temperature rectification in a multi-pressure double column cycle including the steps of compressing a major air stream to a higher pressure approximating that of the higher pressure rectification stage; compressing a minor air stream to a low pressure intermediate the pressures of the higher and lower pressure rectification stages; cooling said major and minor air streams to temperatures close to their respective condensation temperatures by heat exchange with at least most of the nitrogen and oxygen products, respectively, of the rectification, the major and minor air stream volumes being apportioned for such heat exchanges with the volumes of at least most of the nitrogen and oxygen products, respectively; passing the cold, minor air stream to the lower pressure rectification stage for separation therein; passing at least most of the cold major air stream to the higher pressure rectification stage for partial rectification and condensation therein to form at least a nitrogen-rich liquid and an oxygen-enriched liquid; throttling such liquids to the lower pressure and passing the liquids to the lower pressure rectification stage for separation therein along with the minor air stream to provide said nitrogen and oxygen products.

3. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure double column cycle, in which liquid oxygen from said lower pressure rectification stage is cocurrently evaporated by heat exchange with simultaneously condensing gas in said higher pressure rectification stage so as to form reflux liquid for such stage.

4. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure double column cycle, in which reflux fluid for said higher pressure rectification stage is obtained by condensing higher pressure stage gas by heat exchange with at least two colder fluids, including liquid oxygen which is simultaneously cocurrently evaporated in the higher pressure stage as a product gas, and liquid oxygen which is simultaneously evaporated in the reboiler zone of the lower pressure stage.

5. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure double column cycle in which at least part of the cold major air stream is slightly warmed, expanded from said higher pressure to about said lower pressure with the production of external work, and passed to said lower pressure rectification stage for rectification therein.

6. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure double column cycle, in which gas from said higher pressure rectification stage is condensed by heat exchange with gaseous nitrogen product from said lower pressure rectification stage, and returned to said higher pressure rectification stage.

7. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure cycle, in which at least part of the cold, minor air stream is slightly warmed, expanded from said low pressure to about said lower pressure with the production of external work, and passed to the lower pressure stage for rectification therein.

8. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure cycle in which at least part of the cold, major air stream and at least part of the cold, minor air stream are slightly warmed, expanded from said higher pressure and said low pressure to about said lower pressure with the production of external work, and passed to the lower pressure stage for rectification therein.

9. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure cycle, in which an externally supplied liquid comprising mainly oxygen is cocurrently evaporated by heat exchange with simultaneously condensing gas in said higher pressure rectification stage so as to form reflux liquid for such stage.

10. A process according to claim 2 for the separation of air by low temperature rectification in a multi-pressure cycle, in which liquid oxygen from an external source and from said lower pressure rectification stage are cocurrently evaporated by heat exchange with simultaneously condensing gas in said higher pressure rectification stage so as to form reflux liquid for such stage.

11. A process for the separation of impurity-containing air by low temperature rectification in a multi-pressure double column cycle including the steps of providing a major air stream at a higher pressure approximating that of the higher pressure rectification stage and providing a minor air stream at a low pressure intermediate the pressures of the higher and lower pressure rectification stages; separately cooling said major and minor air streams to temperatures close to their respective condensation temperatures by heat exchange with at least most of the nitrogen and oxygen products, respectively, of the rectification, the major and minor air stream volumes being apportioned for such heat exchanges with the volumes of at least most of the nitrogen and oxygen products, respectively; expanding the cold, low pressure minor air stream to about the lower pressure with the production of external work and passing such work expanded air to the lower pressure stage for rectification therein; passing at least most of the cold, major air stream to the higher pressure rectification stage for partial rectification and condensation therein to form a nitrogen-rich liquid and an oxygen-enriched liquid; and condensing higher pressure stage gas so as to provide higher pressure stage reflux liquid by heat exchange with liquid oxygen from the lower pressure stage which is simultaneously cocurrently evaporated in the higher pressure stage to form product oxygen, and heat exchange with liquid oxygen which is simultaneously evaporated in the reboiler zone of the lower pressure stage; throttling the nitrogen-rich and oxygen-enriched liquids to the lower pressure and passing such liquids to the lower pressure rectification stage for separation therein along with the minor air stream to provide said nitrogen and oxygen products.

12. Apparatus for the separation of impurity-containing air by low temperature rectification in a rectification column including means by which a major air stream is provided at a higher pressure approximating that of the higher pressure section of the column; means by which

a minor air stream is provided at a low pressure intermediate the pressures of the higher and lower pressure sections of such column; heat exchange means for separately cooling said major and minor air streams to temperatures close to their respective condensation temperatures by at least most of the nitrogen and oxygen products, respectively, of the rectification so as to remove most of the impurities from the air streams; means for removing the remaining impurities from the cold, minor air stream and means for passing such stream to said lower pressure section of the rectification column for separation therein; means for removing the remaining impurities from the cold, major air stream and means for passing at least most of such stream to said higher pressure section of the rectification column for partial rectification and condensation therein to form at least a nitrogen-rich liquid and an oxygen-enriched liquid; means for throttling such liquids to the lower pressure; and means for passing the liquids to said lower pressure section of said rectification column along with said minor air stream to provide said nitrogen and oxygen products.

13. Apparatus according to claim 12 for the separation of impurity-containing air by low temperature rectification in a rectification column in which heat exchange means are provided for cocurrently evaporating liquid oxygen from said lower pressure section of said rectification column by heat exchange with gas in said higher pressure section so as to form reflux liquid for the higher pressure section.

14. Apparatus according to claim 12 for the separation of impurity-containing air by low temperature rectification in a rectification column including heat exchange means for slightly warming at least part of the cold cleaned major air stream, turbine means for expanding such part from said higher pressure to about said lower pressure with the production of external work, and means for passing such work expanded part to said lower pressure section of said rectification column for separation therein.

15. Apparatus according to claim 12 for the separation of impurity-containing air by low temperature rectification in a rectification column including heat exchange means for slightly warming at least part of the cold cleaned minor air stream, turbine means for expanding such part from said low pressure to about said lower pressure with the production of external work, and means for passing such work expanded part to said lower pressure section of said rectification column for separation therein.

16. Apparatus according to claim 12 for the separation of impurity-containing air by low temperature rectification in a rectification column including heat exchange means for slightly warming at least part of the cold cleaned major air stream and the cold clean minor air stream, turbine means for expanding said part of the major air stream from said higher pressure to about said lower pressure with the production of external work, turbine means for expanding said part of the minor air stream from said low pressure to about said lower pressure with the production of external work, and means for passing such work expanded parts to said lower pressure section of said rectification column for separation therein.

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