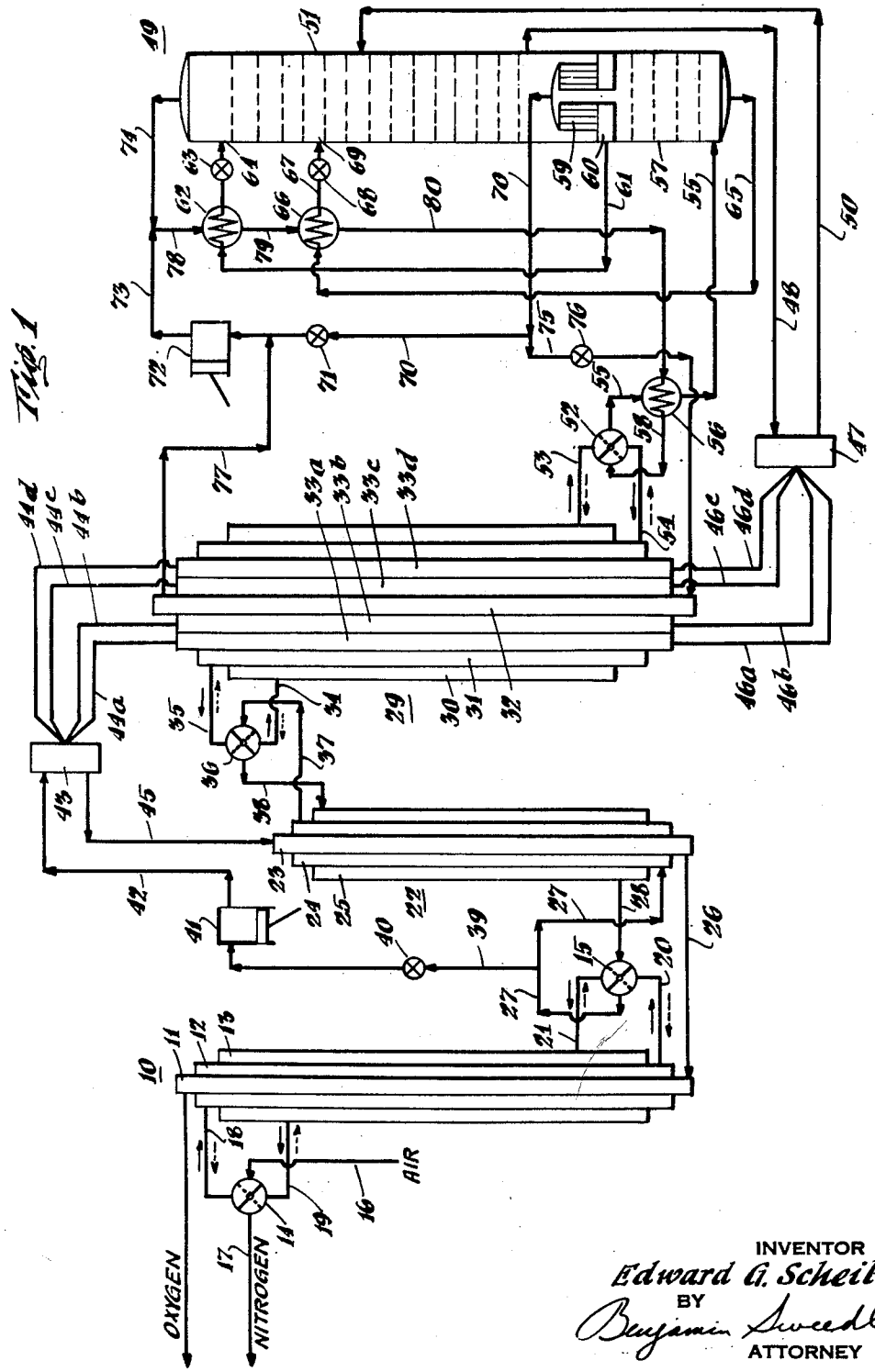
April 11, 1950 E. G. SCHEIBEL 2,504,051

PROCESS FOR PRODUCING OXYGEN BY LIQUEFACTION OF AIR IN WHICH A PORTION OF THE AIR IS EXPANDED TO SUPPLY REFRIGERATION WITHOUT LOSS OF OXYGEN CONTENT OF THE AIR

Filed April 30, 1947 2 Sheets-Sheet 1

Fig. 1



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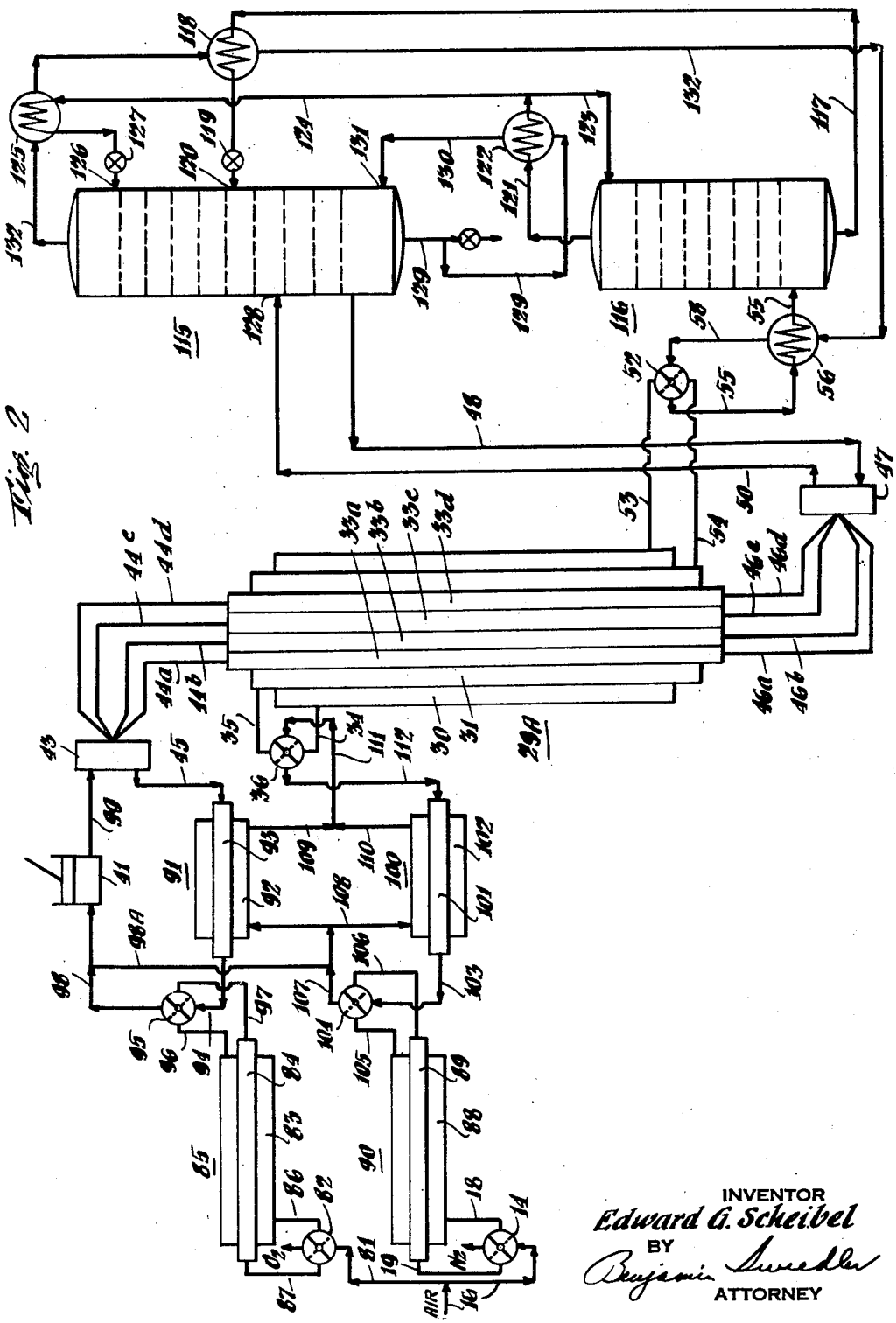


Fig. 2

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PROCESS FOR PRODUCING OXYGEN BY LIQUEFACTION OF AIR IN WHICH A PORTION OF THE AIR IS EXPANDED TO SUPPLY REFRIGERATION WITHOUT LOSS OF OXYGEN CONTENT OF THE AIR

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Application April 30, 1947, Serial No. 745,002

16 Claims. (Cl. 62—175.5)

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This invention relates to the production of oxygen by the liquefaction and rectification of air, and more particularly to a method of obtaining oxygen in high yield without the use of chemical reagents to effect the removal of carbon dioxide present in air.

All temperatures herein are in degrees F. and pressures in pounds per square inch gauge.

Oxygen is commonly produced by partial liquefaction of air and rectification at low temperatures; preferably rectification is conducted in two stages at different pressures. The refrigeration necessary for liquefaction is supplied to the air, after it has been compressed and water-cooled to approximately room temperature, by indirect heat exchange with the effluent products of rectification. However, an additional amount of refrigeration must be supplied to compensate for cold losses resulting from the difference in enthalpy between the incoming air and the outgoing products of rectification and for heat leaks into the system. Methods of supplying this refrigeration heretofore used involve compressing at least a portion of incoming air to pressures as high as 3000 pounds and expanding with or without the performance of work to produce a temperature drop; or compressing all the incoming air to about 600 pounds and after the air has been partially cooled by the products of rectification expanding a portion of the air. These methods are wasteful from the standpoint of compressor energy and require a great deal of equipment in the form of extra compressors, intercoolers and expanders.

For economical operation it is essential to recover the cold content of the outgoing products of rectification. This is usually accomplished by passing these products in heat transfer relationship with the incoming air. In older systems, in order to avoid deposition of frost and solid carbon dioxide in the tubular countercurrent heat exchangers through which the air is passed in indirect heat exchange relation with the outgoing products of rectification, the air is treated in driers and caustic scrubbers to remove water and carbon dioxide prior to admittance of the air into the heat exchangers. Even with this treatment, the exchangers had to be thawed out regularly to remove the frost (which term is used in a generic sense to include both snow and ice) which caused stopping up of the apparatus.

More recently it has been suggested to use cold accumulators or regenerators (hereinafter referred to as heat exchangers) of large cold absorbing capacity through which the warm incoming air and the cold products of rectification

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are alternately passed with periodically reversed operation so that streams of warm air are flowed through the same packing-filled spaces that the cold separated oxygen and nitrogen traversed during the previous step in the process, the high boiling impurities deposited in these spaces during the passage of air therethrough being removed by sublimation during the subsequent flow in a reverse direction of the products of rectification. The use of these reversing heat exchangers in a process in which the air is compressed to relatively high pressure results in more costly operation from the standpoint of horsepower requirements because upon every reversal, which may take place every three minutes, the volume of compressed air in the heat exchangers is lost and must be again replaced. Moreover, in the operation of such reversing heat exchangers it is important not to let the temperature at the cold end of the exchangers drop to a point where a part of the air becomes liquid because this liquid adheres to the surface of the exchangers and is wasted upon reversal of flow.

Copending applications Serial No. 632,860 and No. 632,861, filed December 5, 1945, on Frank J. Jenny and my joint inventions disclose and claim processes for producing oxygen by liquefaction and rectification of air involving the flow of air under pressure through the heat exchange paths of two or more reversing heat exchangers in series, each exchanger containing two other paths through which are passed, respectively, streams of oxygen and nitrogen products of rectification in heat exchange relation with the air passing therethrough. One of the streams flowing between the first exchanger and the second exchanger is refrigerated by expanding a minor portion of the total air introduced into the process, say from 5% to 10% by volume, preferably about 7%, to produce refrigeration which is imparted to the rectification products prior to their flow through the first heat exchanger, the amount of cold thus introduced into the process being adequate to compensate for cold losses resulting from the difference is enthalpy between the air introduced into and the products of rectification withdrawn from the process and for heat leaks into the system. In the processes of these patent applications the refrigeration produced by expanding a minor portion of the air is introduced into the processes by mixing the cold expanded air with the effluent nitrogen product of rectification and passing the resultant mixture in heat exchange relation with the incoming air. Thereafter the resulting nitrogen stream containing the minor portion of air mixed therewith is

vented to the atmosphere. This mode of operation necessarily involves a loss of the oxygen content of the minor portion of the air stream expanded to produce the refrigeration which is introduced into these processes to compensate for cold losses resulting from the difference in enthalpy between the air introduced into and the products of rectification withdrawn from these processes and for heat leaks into the system.

This invention is in the nature of an improvement on the inventions of the aforesaid applications.

Among the objects of this invention is to provide a process for producing oxygen by the liquefaction and rectification of air in which (1) carbon dioxide and preferably also other condensible constituents, notably moisture, are removed from the air without the use of chemical reagents, (2) air is compressed to relatively low pressures so that power losses are minimized on reversal of flow through the reversing heat exchangers, the reversing exchangers being operated so that carbon dioxide and preferably also moisture are substantially completely removed from the air during its flow therethrough during one step of the process and upon reversal the carbon dioxide and the moisture, if any, deposited in the exchangers during the preceding step are substantially completely removed and this without liquefaction of air taking place in the exchangers, and (3) the refrigeration necessary to compensate for cold losses resulting from the difference in enthalpy between the incoming air and the outgoing products of rectification and for heat leaks into the system is supplied by expanding a minor portion of the air and this without entailing any loss of the oxygen content of the air thus expanded.

Other objects and advantages of this invention will be apparent from the following detailed description thereof.

In accordance with this invention a stream of air under pressure is passed through a path in a heat exchange zone through another path of which is passed a stream of rectification product in heat exchange relation with the air to cool the air. A minor portion of the thus cooled air is expanded to produce the refrigeration necessary to compensate for cold losses resulting from the difference in enthalpy between the air introduced into and the products of rectification withdrawn from the process and for heat leaks into the system. The expanded air is then passed through a path in another heat exchange zone through other paths of which are passed a stream consisting of the remainder of the air and at least two streams of rectification product, such as a stream of nitrogen and one or more streams of oxygen rectification product from the rectification system. The temperature at the cold end of this other heat exchange zone is maintained such as to effect the substantially complete removal of carbon dioxide from the air streams flowing therethrough and still avoid liquefaction of the air. From this other zone, the expanded air is passed to the low pressure stage of the rectification system where its oxygen content is recovered; the other stream of air passing through this zone consisting of the remainder of the air which was not expanded is fed into the high pressure stage of the rectification system. Periodically the flow of the expanded air stream and one of the rectification product streams passing through the other zone is reversed and also the flow of the stream consisting of the remainder of the air and a rectification product stream is reversed through the respective paths in the other zone. Upon each reversal the rectification product streams substantially completely remove the carbon dioxide deposited in those paths in the other zone which constituted the air flow paths during the preceding step of the process.

More specifically, in accordance with a preferred embodiment of this invention, a stream of air at a pressure of about 60 to about 100 pounds is passed through a path in a first heat exchange zone. Streams of oxygen and nitrogen rectification products are passed through two other paths in this heat exchange zone in heat exchange relation with the air, thereby cooling the air. A minor portion of the air thus cooled is expanded to a pressure of from about 4 to about 10 pounds and the expanded air passed through a third heat exchange zone. A stream consisting of the remainder of the air, and herein referred to as the high pressure air stream to distinguish it from the expanded air stream, is passed through a path in a second heat exchange zone in heat exchange relation with streams of oxygen and nitrogen rectification products and then through a path in the third heat exchange zone. Through this third heat exchange zone are also passed a stream of nitrogen rectification product and a plurality, preferably three, streams of oxygen rectification product, all of the paths in this third heat exchange zone being in heat exchange relation with each other.

The temperature conditions maintained at the cold end of the respective heat exchange zones are such that substantially all moisture is condensed from the air and removed therefrom during the flow of the air through the first heat exchange zone, little or no condensation of condensible constituents takes place during the flow of the air through the second heat exchange zone and substantially all carbon dioxide is removed from the air during its flow through the third heat exchange zone without any substantial liquefaction of the air taking place in this zone.

Periodically the flow of high pressure air and nitrogen is reversed in the first heat exchange zone; the flow of the high pressure air and nitrogen is reversed in the third heat exchange zone and the flow of the expanded air and one of the oxygen streams reversed in the third heat exchange zone. The expanded air upon each succeeding reversal flows through a different path in the third zone previously traversed by oxygen. Thus, when four paths *a*, *b*, *c* and *d* are employed for the oxygen and expanded air streams, the expanded air is caused to flow upon each succeeding reversal first through path *a*, then *b*, then *c*, and then *d* before again flowing through *a*, etc., while oxygen flows through the other three paths. Hence, the oxygen flows through each path in the third zone for a period of time three times as long as the flow of the expanded air therethrough. This factor and the maintenance of a temperature difference between (1) the entering streams of products of rectification and (2) the exiting expanded air and high pressure air streams from the third zone within the range of 5° to 10° F., preferably about 6° to 8° F., insures the complete purging of condensed carbon dioxide from the flow paths in the third zone through which the expanded air and the high pressure air passed during the preceding step of the process. This temperature difference is the difference between the temperature of the high

pressure air or of the expanded air (both air streams at the colder end of the third zone being at the same temperature) and the weighted average temperature of the products of rectification, all temperatures being taken at the colder end of the third zone. The weighted average temperature of the products of rectification is calculated by multiplying the temperature of the oxygen product stream by the volume percentage of the stream based on the combined volume of the products of rectification and adding thereto the corresponding figure obtained by multiplying the temperature of the nitrogen product stream by its volume percentage. Thus, for example, if the rectification system is operated to produce two streams of substantially pure oxygen and pure nitrogen, the weighted average temperature of the two streams would be approximately the sum of 20% of the oxygen stream temperature and 80% of the nitrogen stream temperature.

From the third heat exchange zone the expanded air is passed to the low pressure stage of a two-stage rectification system. The high pressure air stream is introduced into the high pressure stage of this system. The nitrogen and oxygen rectification products from the system, as hereinabove disclosed, are passed through the exchangers to impart their cold content to the air introduced as hereinabove described into the rectification system.

As above indicated, periodically, say every three minutes, the flow of the high pressure air stream and nitrogen in the third heat exchange zone and the flow of high pressure air and nitrogen in the first heat exchange zone are reversed through their respective paths so that upon each reversal the air flows through the paths in these two zones through which during the preceding step the nitrogen had passed and the nitrogen flows through the paths in these two zones through which had previously passed the air. Likewise in the third zone a reversal of flow takes place between the expanded air stream and one of the oxygen streams. The nitrogen and oxygen remove by sublimation the carbon dioxide deposited during the preceding step in the third zone and the nitrogen also removes frost deposited during the preceding step in the first zone. If desired, the oxygen may also be used to remove frost deposited in the first heat exchange zone. Operating in this manner, complete purging of carbon dioxide and frost is obtained upon each reversal of flow so that the equipment may be operated continuously. No such reversal of flow takes place through the second zone in the usual operation of the process. Due to the use of an intermediate or second non-reversing heat exchange zone, the volume loss of air under pressure upon each reversal of flow is reduced by an amount equal to the volume of this intermediate non-reversing heat exchange zone. Thus, power losses are minimized.

In the accompanying drawings forming a part of this specification and showing for purposes of exemplification preferred layouts of equipment for practicing the process of this invention:

Figure 1 illustrates diagrammatically a preferred layout of apparatus for practicing the process of this invention; and

Figure 2 illustrates a modified arrangement of apparatus for practicing this invention.

It will be understood the drawings illustrate diagrammatically preferred apparatus for practicing this invention and that the invention may be carried out in other apparatus. For example,

any desired number of reversing exchangers may be used in lieu of the reversing exchangers shown in the drawings; each of the exchangers of the drawings may be replaced by two or more smaller exchangers placed in series and/or parallel, if desired. Other rectification systems may be used in lieu of those shown in the drawings, thus, for example, the means for purging the high pressure stage to remove incondensible gases, such as hydrogen, neon and helium, may be omitted from the rectification system shown in Figure 1, or may be employed in the rectification system shown in Figure 2, or the rectification system shown in Figure 1 may be employed with the exchanger system of Figure 2 and vice versa, the rectification system of Figure 2 employed with the exchangers shown in Figure 1. Hence, the scope of this invention is not confined to the embodiments herein described. Furthermore, it will be understood that the equipment throughout is thermally insulated to minimize loss of cold.

In the drawings like reference characters indicate like parts.

Referring to Figure 1, **10** is a heat exchanger which may be of any well known type. In the embodiment shown in the drawings it consists of a single shell in which are provided three flow paths, namely, interior path **11** and concentric paths **12** and **13** disposed in heat exchange relation with each other. The heat exchanger has in each of the paths suitable fins of heat conducting material, e. g., copper or aluminum, promoting rapid and efficient heat exchange between the gaseous media flowing therethrough. For purposes of illustration and in the interests of simplicity, each flow path in an exchanger is shown on the drawings as consisting of a single tube, the several paths being disposed concentrically. Actually, however, each path in each exchanger may comprise a multiplicity of tubes for flow therethrough. One form of exchanger which may be used in practicing the process of this invention is disclosed and claimed in application Serial No. 676,142, filed June 12, 1946. As the construction of the heat exchanger per se does not form a part of this invention and as it may be of any well-known type it is believed further description thereof is unnecessary.

Path **11** is the oxygen flow path. No reversal of flow through this path takes place. Paths **12** and **13** are the paths through which air and nitrogen flow, the flows of these two media through their respective paths being periodically reversed so that during one step of the process air flows through path **12** and nitrogen through path **13**, and upon reversal during the succeeding step air flows through path **13** and nitrogen through path **12**. Reversal of flow is accomplished by suitably positioning the compound reversing valves **14** and **15** which may be of any well-known type. Valve **14** is disposed in the pipe line system consisting of (*a*) air inlet pipe **16** leading into valve **14**, (*b*) nitrogen exit line **17** leading to any suitable point of nitrogen disposal and (*c*) pipe lines **18** and **19** leading to one end of paths **12** and **13**, respectively. Lines **20** and **21** lead from the other end of the exchanger from paths **12** and **13**, respectively, to valve **15**.

A second heat exchanger **22** is provided in the form of a shell having therein paths **23**, **24** and **25** provided with fins to promote heat exchange as in the case of the exchanger **10**. Path **23** is the path through which the oxygen product of rectification flows and is connected with pa

11 of exchanger 10 by line 26. Path 24 is the air path connected with valve 15 by line 27 and path 25 is the nitrogen path connected with reversing valve 15 by a line 28.

A third heat exchanger 29 is provided in the form of a shell having seven flow paths 30, 31, 32 and 33a, 33b, 33c and 33d, each provided with fins to promote heat exchange as in the case of the exchangers 10 and 22. Paths 30, 31 and 32 are shown as concentric paths; paths 33a, 33b, 33c and 33d may be segments of the concentric path between the outer wall of path 32 and the inner wall of path 31. Path 32 is the path through which a portion of the nitrogen may be passed to preheat it prior to introduction into an expander as hereinafter more fully disclosed. If a rectification system not equipped to expand high pressure nitrogen containing incondensible gases is employed, this path may be eliminated from the exchanger.

Paths 30 and 31 are the flow paths through which high pressure air and nitrogen flow, the flow of these two media through their respective flow paths being periodically reversed. The upper portions of paths 30 and 31 communicate respectively with lines 34 and 35, which in turn communicate with a compound reversing valve 36 which may be of the same type as the reversing valves 14 and 15. A line 37 connects reversing valve 36 with the upper portion of flow path 24 in exchanger 22 and a line 38 extends from reversing valve 36 to the upper portion of flow path 25 of exchanger 22.

Leading from line 27 is a branch line 39, flow through which is controlled by a valve 40. By suitably positioning valve 40, a minor portion of the total air introduced into the process, say from about 5% to about 10%, preferably about 7%, enters expander 41 which may be a centrifugal expander or turbine of any well-known type. Line 42 leads from this expander to a flow controller 43 which may be any suitable valve mechanism for controlling the flow of the expanded air so that it enters only one of the lines 44a, 44b, 44c and 44d communicating respectively with the tops of the flow paths 33a, 33b, 33c and 33d. A line 45 leads from the flow controller 43 to the top of flow path 23 of exchanger 22. Flow controller 43, when placing line 42 in communication with one of the lines 44a, 44b, 44c or 44d, at the same time places the other three lines of the last mentioned group in communication with line 45 so that flow of expanded air from line 42 takes place through one of the lines 44a, 44b, 44c or 44d, while flow of oxygen from the other three lines takes place through line 45 communicating with the oxygen path 23. Flow controller 43 successively places line 42 in communication first with say line 44a, then upon the next reversal step of the process with line 44b, upon the next reversal with line 44c, upon the next reversal with line 44d, upon the next reversal again with line 44a, etc. Hence, oxygen flows through each of the flow paths 33a, 33b, 33c and 33d communicating with the lines 44a, 44b, 44c and 44d, respectively, for a period of time three times as long as the flow of expanded air through each of these flow paths.

The base of flow paths 33a, 33b, 33c and 33d communicate with lines 46a, 46b, 46c and 46d, respectively, which lead into flow controller 47 of the same general type as 43. An oxygen inlet line 48 from the rectification system 49 leads into the flow controller 47. An expanded air exit line 50 leads from flow controller 47 to the low pressure stage 51 of the rectification system 49.

Reversing valve 52 of the same general type as reversing valve 36 hereinabove described is connected with the base of the flow paths 30, 31 through lines 53, 54, respectively. A high pressure air line 55 leads from valve 52 through a non-reversing heat exchanger 56 to the high pressure stage 57 of the rectification system 49. A nitrogen line 58 leads into reversing valve 52.

The rectification system of Figure 1 comprises a two-stage rectification column 49, the lower section 57 of which is operated at a pressure of from 60 to 100 lbs., preferably about 70 to 75 lbs., and the upper section 51 of which is operated at a pressure of from about 4 to about 10 lbs., preferably about 5 lbs. This column, as is customary, is provided with rectification plates of the bubble cap or other desired type. The lower section 57 of the column communicates with a condenser 59 and has a liquid collecting shelf 60 disposed immediately below the condenser 59 for collecting liquid nitrogen; pipe line 61 leads from this shelf 60 to a non-reversing heat exchanger 62 which in turn communicates through a pressure reducing valve 63 with the top portion of the upper section 51 at 64. Condenser 59 acts as a reboiler for the upper section 51 of the column.

From the base portion of the lower section 57 a pipe line 65 for the flow of crude oxygen (containing approximately 40% oxygen) passes to a non-reversing heat exchanger 66 which communicates through pipe line 67 having a pressure reducing valve 68 therein with the low pressure section 51 at an intermediate point 69. Line 70 leads from the top of the condenser 59 and has a regulating valve 71 therein. This line communicates with an expander 72 which discharges into line 73 communicably connected with a line 78 hereinafter described.

Preferably, line 70 is provided with a branch line 75 having a regulating valve 76 and leading to the flow path 32 disposed in heat exchanger 29 in indirect heat exchange relation with the other flow paths in this exchanger. A line 77 leads from path 32 back to line 70 at a point between valve 71 and expander 72. Regulating valves 71 and 76 disposed in lines 70 and 75, respectively, regulate the proportions of the nitrogen stream flowing from condenser 59 which are passed directly to expander 72 and indirectly through path 32 in exchanger 29.

By the arrangement of lines hereinabove described, a minor portion of the total nitrogen introduced into the process passes through line 70 and, preferably, of the portion thus withdrawn a minor portion, say about 10%, passes through line 75, path 32 and line 77, entering line 70 where it mixes with the remainder of the nitrogen withdrawn from the condenser 59. The portion of the nitrogen passing through path 32 is warmed by indirect heat exchange with the other streams flowing through exchanger 29, and upon mixing with the remainder of the nitrogen enters expander 72 at a temperature sufficiently high to avoid condensation or formation of liquid nitrogen in the expander. In a preferred embodiment of the invention, from about 1% to about 15% by volume of the total nitrogen introduced into the process and containing incondensibles, such as hydrogen, helium and neon, is passed through line 70 and of this quantity about 10% by volume passes through flow path 32 and 90% by volume continues through line 70 into expander 72.

The nitrogen stream refrigerated as a result of the expansion flows from the expander 72

through line 73 into line 78 where it mixes with the nitrogen stream flowing through line 74 leading from the top of low pressure section 51. The total nitrogen then flows through heat exchanger 62 in indirect heat exchange relation with the nitrogen passing through this exchanger and thereafter flowing through reducing valve 63 into the top portion of low pressure section 51. From heat exchanger 62 the nitrogen stream flows through line 79 into and through heat exchanger 66 where it flows in indirect heat exchange relation with the crude oxygen flowing therethrough to low pressure section 51. From the heat exchanger 66 the nitrogen stream passes through line 80 into and through heat exchanger 56 where it passes in indirect heat exchange relation with high pressure air flowing into and through this exchanger by way of line 55. From the heat exchanger 56 the nitrogen stream flows through line 58 into the compound reversing valve 52, thence through line 53 or 54 and path 30 or 31 of heat exchanger 29, through line 34 or 35, valve 36, line 38, path 25 of exchanger 22, line 28, valve 15, line 20 or 21, path 12 or 13 of heat exchanger 10, line 18 or 19, and finally through compound valve 14 to the atmosphere.

The flow of the nitrogen through path 12 or 13 of heat exchanger 10 and through 30 or 31 of heat exchanger 29 will, of course, depend upon the setting of valves 14, 15, 36 and 52. When set in the position indicated by the full lines on Figure 1, nitrogen flows through path 31 while air flows through 30 in exchanger 29 and nitrogen flows through path 13 while air flows through path 12 of exchanger 10. Upon reversal, when the valves occupy the position indicated by the dotted lines, the nitrogen flows through path 30 while air flows through path 31 of exchanger 29 and nitrogen flows through path 12 and air through path 13 in exchanger 10. It is advisable to operate exchanger 22 without reversal of flow.

The product oxygen stream is withdrawn from the rectification system through line 48, passes to flow controller 47 from which it flows through three of the flow paths 33*a*, 33*b*, 33*c* and 33*d*, as hereinabove described, and then flows through controller 43, line 45, and paths 23 and 11 in exchangers 22 and 10, respectively. Flow reversal of oxygen and expanded air takes place periodically in exchanger 29 as hereinabove disclosed. The oxygen flow through exchangers 10 and 22 throughout the process takes place through the same flow paths, i. e., no reversal of flow for oxygen takes place.

In the modification of Figure 2, instead of having the air and oxygen and nitrogen rectification products pass through a single pair of exchangers 10 and 22, in series, the air is divided into two streams, one stream passing through a pair of exchangers 85 and 91 in heat exchange relation with the oxygen, and the other stream through a second pair of exchangers 90 and 100 in heat exchange relation with the nitrogen. Also this modification involves a different rectification system as hereinafter more fully described.

In Figure 2, parts which correspond in structure and function with parts of Figure 1 have been given the same reference characters as in Figure 1. In Figure 2, air line 16 is provided with a branch line 81 leading to a reversing valve 82 connected with two reversing flow paths 83, 84, for flow of air and oxygen therethrough, in exchanger 85. Flow path 83 is connected with reversing valve 82 by a line 86 and flow path 84 is connected with this reversing valve by a line 87. Air line 16 leads to reversing valve 14 connected by lines 18 and 19 with reversing flow paths 88 and 89, for flow of air and nitrogen therethrough, in exchanger 90.

In series with exchanger 85 is a non-reversing exchanger 91 having flow paths 92 and 93 therein for flow of air and oxygen, respectively, therethrough. Oxygen line 94 leads from flow path 93 to a reversing valve 95 of the same general type as reversing valves 14 and 82. A line 96 connects this reversing valve with flow path 83 and a line 97 connects it with flow path 84 in exchanger 85. A line 98 leads from reversing valve 95 to expander 41 which is connected by line 99 with the flow controller 43 controlling the flow of expanded air into one of lines 44*a*, 44*b*, 44*c* and 44*d* and the flow of oxygen from the remaining three of this series of four lines into the line 45 leading from the flow controller 43 to the oxygen flow path 93 of exchanger 91. The lines 44*a*, 44*b*, 44*c* and 44*d* lead into flow paths 33*a*, 33*b*, 33*c* and 33*d* of an exchanger 29A which, except that it does not contain a flow path corresponding to path 32 of the exchanger 29 of Figure 1, is substantially the same as exchanger 29 of Figure 1.

An exchanger 100 is connected in series with exchanger 90. This exchanger comprises a nitrogen flow path 101 and an air flow path 102. A line 103 connects the nitrogen flow path 101 with a reversing valve 104 which may be of the same type as reversing valve 95. Lines 105 and 106 connect this reversing valve with flow paths 88 and 89, respectively, of exchanger 90. A line 107 leads from reversing valve 104 to a line 108 communicating with the air flow paths 92 and 102 of exchangers 91 and 100, respectively. Line 98A connecting air lines 98 and 107 serves to distribute the total air between that portion which is expanded in expander 41 and that portion which proceeds through the process as the high pressure air stream. The exit end of the flow paths 92, 102 are provided with exit lines 109, 110 which lead into a line 111 communicating with the reversing valve 36 which is connected by lines 34, 35 with the flow paths 30, 31 in exchanger 29A. A line 112 leads from the reversing valve 36 into the nitrogen flow path 101 of exchanger 100.

In the operation of the exchanger system of Figure 2, as indicated by full line valve settings, about 20% of the air flows through line 81, reversing valve 82, line 86, flow path 83, line 96, valve 95 and line 98. The remainder of the air (about 80%) flows through line 16, valve 14, line 18, flow path 88, line 105, reversing valve 104 and line 107. The two portions of air after being cooled and purged of moisture by passage through exchangers 85 and 90 are brought together through line 98A. Of this total air, about 5% to 10% flows into expander 41, the expanded air flowing through line 99, flow controller 43, one of the lines 44*a*, 44*b*, 44*c*, or 44*d* into and through one of the flow paths 33*a*, 33*b*, 33*c*, or 33d. The unexpanded portion or high pressure air continues its flow to line 108, about 20% thereof passing through flow path 92 and line 109, and 80% through flow path 102 and line 110. Thence, all the high pressure air proceeds through line 111, valve 36, line 34 and flow path 30 of exchanger 29A.

Nitrogen flows through flow path 31, line 35, valve 36, line 112, flow path 101 in exchanger 100,

line 103, reversing valve 104, line 106, flow path 89 in exchanger 90, exiting through line 19 and valve 14. Oxygen flows through three of the paths 33a, 33b, 33c, 33d into three of the communicating lines 44a, 44b, 44c, 44d, controller 43, line 45, flow path 93 in exchanger 91, line 94, valve 95, line 97, flow path 84, exiting through line 87 and valve 82.

Upon reversal, as indicated by the dotted settings of the reversing valves, 20% of the air flows through line 87, flow path 84, line 97, valve 95 and line 98. The remainder of the air flows through line 16, reversing valve 14, line 19, flow path 89, line 106, reversing valve 104 and line 107. The high pressure air flows through flow paths 102 and 92 into and through line 111, reversing valve 36, line 35 into and through flow path 31. The expanded air leaving expander 41 passes through line 99, flow controller 43 and through a different one of the lines 44a, 44b, 44c and 44d; thus, if during a preceding step air had flowed through line 44a, then during the succeeding step the air flows through line 44b into the communicating flow path 33b in exchanger 29A.

Nitrogen flows through flow path 30, line 34, reversing valve 36, line 112, flow path 101, line 103, reversing valve 104, line 105, flow path 88, line 18, exiting through valve 14. Oxygen flows through three of the flow paths 33a, 33b, 33c and 33d, i. e., if air is flowing through flow path 33b then the oxygen flows through the other three flow paths, controller 43, line 45, flow path 93, line 94, reversing valve 95, line 96, flow path 83, line 86, exiting through valve 82.

It will be noted that flow through the flow paths 92, 93 and 101, 102 of the exchangers 91 and 100, respectively, takes place in the same direction throughout the operation of the process. On the other hand, flow of the nitrogen and air through their respective paths in exchangers 90 and 29A and of the oxygen and air through their respective paths in exchangers 85 and 29A is periodically reversed.

As in the modification of Figure 1, each of the flow paths of Figure 2 is provided with suitable walls and fins of heat conducting material, e. g., copper or aluminum. The various flow paths in the exchangers 85, 90, 91 and 100 are shown arranged in concentric relationship; in exchanger 29A flow paths 30 and 31 are shown concentric and the remaining four flow paths 33a, 33b, 33c and 33d are suitably disposed within the core defined by the inner wall of the flow path 31. It will be understood the showing of the exchangers in the drawing is diagrammatic in character, and that while exchangers 90 and 100 are shown of the same size as 85 and 91, the nitrogen exchangers 90 and 100 should be constructed of a capacity approximately four times the volumetric capacity of the oxygen exchangers 85 and 91 to accommodate the larger volume of nitrogen. The exchanger system of Figure 2 has the advantage over that of Figure 1 in that it involves individual exchangers having less flow paths which are therefore easier and less costly to construct. Each of the exchangers of Figure 2 may be replaced by two or more exchangers in series and/or in parallel. The exchangers of Figures 1 and 2 may be disposed horizontally, or vertically.

The rectification system of Figure 2 comprises two columns 115 and 116. Column 116 is operated at a pressure of from about 60 to about 100 pounds, preferably at about 70 to 75 pounds, and column 115 at a pressure of from about 4 to about

10 lbs., preferably at about 5 lbs. These columns, as customary, are provided with rectification plates of the bubble cap or other desired type. Air is supplied to the base portion of the high pressure column 116 through line 55 which passes through non-reversing heat exchanger 56. Crude oxygen containing approximately 40% oxygen, the rest being chiefly nitrogen, flows from the base of column 116 through line 117 which passes through a non-reversing heat exchanger 118. Upon flow through expansion valve 119 in line 117, the crude oxygen is flashed and enters column 115 at 126.

A line 121 leads from the top of column 116, passes through a non-reversing heat exchanger 122 into a line having one branch 123 for returning liquid reflux comprising chiefly nitrogen to column 116 and another branch 124 passing through a non-reversing exchanger 125 and leading into the low pressure column 115 at 126. An expansion valve 127 is disposed in branch 124.

Expanded air from the flow controller 47 flows through line 58 and enters the low pressure column 115 at 128 where it is rectified to separate the oxygen content thereof from the nitrogen. The base of this column is provided with a line 129 passing through the non-reversing heat exchanger 122, this line having a return portion 130 leading into the low pressure column 115 at 131. The lines 129 and 130 and the cooperating heat exchanger 122 function as a reboiler; liquid oxygen flows from line 129 through exchanger 122 in indirect heat exchange relation with the gaseous stream comprising chiefly nitrogen passing through line 121 which causes vaporization of the liquid oxygen to take place, the oxygen vapors flowing into column 115 at 131. Nitrogen line 132 leads from the top of column 115 through exchangers 125, 118 and 56 and communicates with line 58 leading to the reversing valve 52.

The air entering high pressure column 116 is rectified; crude oxygen is withdrawn from the base of this column through line 117, chilled by flowing in indirect heat exchange relation with the nitrogen stream in exchanger 118, flashed by flowing through expansion valve 119 so that it is still further cooled and introduced into the low pressure column 115 at 120. The gaseous stream consisting chiefly of nitrogen flowing through line 121 leading from the high pressure column 116 passes through heat exchanger 122 in indirect heat exchange relation with the liquid oxygen flowing through this exchanger, this gaseous stream being thus cooled and entering lines 123 and 124. The gaseous stream is thus substantially condensed, the liquid flowing in part through line 123 into column 116 where it serves as reflux liquid. The remainder of the liquid stream predominating in nitrogen flows through line 124 to non-reversing exchanger 125 where it is further cooled by the gaseous nitrogen flowing through this exchanger, then through the expansion valve 127 where it is flashed, thus further cooling it, and enters the low pressure column 115 at 126 as a vapor-liquid mixture in which the liquid predominates. Nitrogen leaves the top of column 115 through line 132, flows through heat exchanger 125 where it gives up a portion of its cold content as hereinabove described to the stream passing through this exchanger and then through the heat exchanger 118 where it cools the oxygen stream flowing through this exchanger. From exchanger 118 the nitrogen stream flows into and through exchanger 56 where it cools the air stream flowing therethrough. From exchanger

56 the nitrogen stream flows through line 58 into the reversing valve 52 into and through one or the other of lines 53, 54, communicating with the flow paths 30, 31 as hereinabove described.

Oxygen from the base of column 115 flows through line 129 and exchanger 122 which functions as a reboiler, the resulting oxygen vapor entering column 115 at 131. The product oxygen stream flows through line 48 leading from the lower portion of column 115 to the flow controller 47 and thence in and through three of the lines 46a, 46b, 46c and 46d communicating with three of the flow paths 33a, 33b, 33c and 33d as hereinabove described.

A desirable operating range involves the introduction of air in the first heat exchange zone at a temperature of 70° to 110° F. and a pressure of about 60 to 100 lbs., and cooling this air to a temperature of −75° to −100° F. in its flow through this zone by countercurrent flow of oxygen and nitrogen products of rectification entering at a temperature of −82° to −112° F. and leaving at a temperature of 60° to 100° F. In the second heat exchange zone, i. e., the non-reversing zone, the high pressure air leaves at a temperature of −180° to −210° F., the oxygen enters at a temperature of −183° to −213° F. and leaves at a temperature of −82° to −112° F. and the nitrogen enters at a temperature of −183° to −213° F. and leaves at a temperature of −82° to −112° F. In the third zone the high pressure and the expanded air streams enter at a temperature of −180° to −210° F. and leave at a temperature of −260° to −280° F. The oxygen enters at a temperature of −288° to −293° F. and leaves at a temperature of −183° to −213° F. The nitrogen enters at a temperature of −265° to −285° F. and leaves at a temperature of −183° to −213° F. The pressure maintained in the high pressure stage is from 60 to 100 lbs., in the low pressure stage from 4 to 10 lbs. The several streams suffer only a small pressure drop in flowing through the exchangers 10, 22 and 29. The amount of air expanded to supply refrigeration necessary to compensate for cold losses resulting from the difference in enthalpy between the air introduced into the products of rectification withdrawn from the process and for heat leaks into the system is generally 5% to 10% of the total air.

One example of the operation of the process of this invention in the apparatus shown in Figure 1 is given below. It will be understood this example is given for purposes of exemplification only and the invention is not limited thereto.

Air under pressure of about 75 lbs. and a temperature of about 100° F. is supplied through line 16, valve 14 and line 18 to heat exchanger 10 flowing through path 12 in which it is cooled to a temperature of −80° F. Of the air flowing through valve 15, 7% by volume is expanded in expander 41, the pressure of the expanded air being about 7 lbs. and its temperature −195° F. This cold expanded air at this temperature is introduced through line 44a into the flow path 33a and passes therethrough, leaving this flow path at a temperature of −275° F., at which temperature it enters low pressure section 51 of the rectification system 49.

The remainder of the air consisting of 93% by volume of the air introduced into the process at a temperature of −80° F. flows through flow path 24 of exchanger 22, exiting from this flow path at a temperature of −195° F., at which temperature it enters flow path 30, leaving this flow path through line 53 at a temperature of −275° F. This air then flows through heat exchanger 56 in heat exchange relation with nitrogen where it is cooled to a temperature of −278° F. and at this temperature and a pressure of about 72 lbs. enters high pressure section 57 of the rectification system 49.

Crude oxygen at a temperature of −280° F. and a pressure of 72 lbs. leaves the base of section 57 through line 65, flows through heat exchanger 66 where its temperature is reduced to −289° F. and upon flow through the pressure reducing valve 67 is flashed, entering low pressure section 51 at a temperature of −310° to −315° F. and a pressure of 5 lbs. Oxygen is withdrawn through line 48 at a temperature of −292.5° F. and a pressure of 5 lbs., flows through lines 46b, 46c and 46d into and through flow paths 33b, 33c and 33d, lines 44b, 44c and 44d, its temperature being increased to −200° F. The oxygen at this temperature enters path 23 of heat exchanger 22, leaving this path at a temperature of −92° F. and then flows through path 11 of heat exchanger 10, leaving this path at a temperature of 90° F. and a pressure of 1 lb.

Nitrogen at a temperature of about −286.5° F. and a pressure of 72 lbs. in amount equal to 12.5% by volume of the total nitrogen introduced into the process is withdrawn through line 70. Of the nitrogen flowing through line 70, 10% passes through line 75 and path 32 in heat exchanger 29, its temperature being increased to −200° F. The remaining 90% of the nitrogen flows through valve 71 in line 70 and is mixed with the other 10% nitrogen, the temperature of the mixture being about −280° F., at which temperature it enters the expander 72. The nitrogen stream leaves the expander 72 at a pressure of 5 lbs. and a temperature of −315° F. The expanded nitrogen flows through line 73 and becomes mixed with nitrogen at a temperature of −315.5° F. and a pressure of 5 lbs. flowing through line 74. The resulting nitrogen stream passes through exchanger 62 in indirect heat exchange relation with nitrogen employed as reflux in column 51, its temperature being thereby increased to −306° F., while the temperature of the nitrogen flowing through line 61 (pressure of 72 lbs.) and exchanger 62 is reduced to −300° F. This latter nitrogen by expansion through valve 63 has its pressure reduced to 5 lbs. and its temperature to −315.5° F.

The nitrogen product of rectification then flows through exchanger 66 where its temperature is increased to −293° F. The crude oxygen stream flowing through exchanger 66 is thereby cooled from a temperature of −280° F. to a temperature of −289° F. The nitrogen then flows through exchanger 56 in heat exchange relation with the air, the nitrogen stream temperature being thereby increased to −279° F. at which temperature it flows through reversing valve 52 into the flow path 31 of exchanger 29 and exits from this flow path at a temperature of −200° F. From exchanger 29 the nitrogen flows through reversing valve 36, flow path 25 in exchanger 22, its temperature being thereby increased to −92° F. It then flows through line 28, reversing valve 15, line 21, flow path 13, from which path it leaves at a temperature of about 90° F. and a pressure somewhat above atmospheric, say 1 lb. At this pressure the nitrogen is vented to the atmosphere, thereby venting the incondensible gases such as hydrogen, helium and neon removed from the high pressure stage of the rectification system.

It will be noted that in the above example, at the colder end of heat exchanger 29 the nitrogen is at a temperature of −279° F., and the oxygen is at a temperature of −292.5° F.; thus the weighted average temperature of the oxygen and nitrogen at this point is −282° F. The high pressure air stream and the expanded air stream at this point are at a temperature of −275° F. A temperature difference of about 7° F. is therefore maintained at this point between the weighted average temperature of the nitrogen and oxygen streams and the air streams.

Upon reversal, as shown by the dotted arrows and valve settings, which may take place every three minutes, the air flows through paths 13 and 31 in exchangers 10 and 29. The nitrogen flows through paths 30 and 12 of exchangers 29 and 10, respectively. The oxygen flows through, say, paths 33*a*, 33*c* and 33*d* in exchanger 29, while the expanded air flows through path 33*b* of this exchanger. The flow is substantially otherwise the same and the temperature and pressure conditions remain the same. The nitrogen in its flow through path 30 of heat exchanger 29 and the oxygen in its flow through path 33*a* of heat exchanger 29 remove by sublimation the carbon dioxide deposited in these paths by the high pressure air stream and the expanded air during the preceding step. Likewise the nitrogen in its flow through path 12 of heat exchanger 10 removes from this path the frost deposited therein from the air during the preceding step. Thus in the continued operation, upon each reversal the nitrogen effects removal of the carbon dioxide and frost deposited in the paths through which the high pressure air had passed during the preceding step of the process.

When the process of this invention is carried out with the use of intermediate non-reversing exchangers, the power requirements are diminished by an amount equal to the power required to compress to a pressure of 60 to 100 lbs. a volume of air corresponding to the volume of the air flow paths through the intermediate non-reversing exchangers. Moreover, by operating under the temperature conditions set forth above, substantially all moisture is removed from the air in exchanger 10, chiefly in the form of frost, i. e., as snow or ice; all carbon dioxide is removed from the air in exchangers 29 and 29A and little or no condensation takes place in exchangers 22, 91 and 100, thereby permitting continuous operation of the equipment. It will be understood that while in normal operation no reversal of flow takes place in exchangers 22, 91 and 100, as a precautionary measure to insure that the air flow paths in these exchangers remain in unobstructed condition, occasionally, say about once a week or month, flow of air through flow path 25 and of nitrogen through flow path 24 in exchanger 22 may be effected; flow of air through path 102 and of nitrogen through path 101 in exchanger 100 may be reversed and flow of oxygen through path 93 and of air through path 92 of exchanger 91 may be reversed, these exchangers being provided with suitable reversing valve mechanism (not shown) for this purpose.

By providing a plurality, preferably three, of flow paths for flow of oxygen and one flow path for flow of expanded air through exchanger 29 or 29A and reversing the flow so that the stream of expanded air flows through one of these three flow paths while one of the oxygen streams flows through the path through which had previously passed the expanded air, the flow of oxygen

through each of these four flow paths takes place for a period of time approximately three times as long as the flow of air therethrough. This insures complete purging of carbon dioxide from these flow paths. Since about 7% of the total air is expanded to supply the refrigeration necessary to compensate for cold losses resulting from the difference in enthalpy between the air introduced into and the products of rectification withdrawn from the process and for heat leaks into the system, and since substantially all of the oxygen content of the air is recovered, the volume of oxygen recovered is approximately three times the volume of expanded air, both being at about the same pressure. Accordingly, the utilization of four flow paths in exchanger 29 or 29A, three of which are employed for flow of oxygen therethrough and the fourth for flow of expanded air, simplifies the design of the exchanger since it permits the utilization of flow paths for the expanded air and oxygen of the same volumetric capacity.

In accordance with this invention, only about 7% of the total air passes through the oxygen flow paths, so that only 7% of the total carbon dioxide content of the air is introduced into these oxygen streams. The amount of carbon dioxide contamination thus introduced does not render the oxygen objectionable for commercial use.

It will be noted that when operating in accordance with this invention substantially complete removal of carbon dioxide takes place from the high pressure and expanded air streams prior to their introduction into the rectification system permitting efficient rectification of the air to produce oxygen. Moreover, the refrigeration necessary to compensate for cold losses resulting from the difference in enthalpy between the incoming air and the outgoing products of rectification and for heat leaks into the system is supplied by expanding a minor portion of the chilled compressed air and this without loss of the oxygen content of the expanded air.

In the operation of the process of this invention it is preferred to effect removal of moisture and carbon dioxide both in accordance with the process of this invention. It will be understood, however, that, if desired, the moisture may be removed from the air by any conventional means and dry air containing carbon dioxide passed through the exchanger or exchangers as hereinabove disclosed. In the event that dry air is supplied to the exchanger system similar to that of Figure 1, for example, reversing valves 14 and 15 may advantageously be omitted, since it will not be necessary to reverse flow through exchanger 10.

The expressions "reversing the flow of air and nitrogen" and "reversal" are used herein in the sense commonly employed in this art, namely, to mean the switching of the flow of two streams, for example, the air and the nitrogen or oxygen streams, so that upon each "reversal" the air flows through the path through which had previously flowed the nitrogen or oxygen and the nitrogen or oxygen flows through the path through which had previously flowed the air. Reversal of the flow of high pressure air and nitrogen passing through the reversing exchangers 10 and 29 of Figure 1, or of high pressure air and oxygen passing through exchanger 85 of Figure 2, need not be synchronized with reversal of the flow of expanded air and oxygen in exchanger 29 of Figure 1 of 29A of Figure 2. Furthermore, these two types of reversal need not be of the same duration. Thus, for example, the flow of high pressure air and nitrogen

through exchangers 18 and 28 may be reversed every three minutes, while the flow of expanded air and oxygen through exchanger 28 may be reversed every five minutes. The particular time cycle for each reversal will depend on the exchanger design and should be selected so as to give most efficient operation of the exchanger.

Since certain changes may be made in carrying out the above processes without departing from the scope of the invention, it is intended that all matter contained in the above description shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a process for producing oxygen by the liquefaction and rectification of air, the steps which comprise passing a stream of air under pressure through a path in a heat exchange zone, passing a stream of rectification product through another path in said heat exchange zone in heat exchange relation with the air passing therethrough to cool said air stream, expanding a minor portion of the thus cooled air stream, passing the expanded air through a path in another heat exchange zone, passing through paths in said other heat exchange zone in heat exchange relation with said expanded air a stream consisting of the remainder of the air and at least two streams of rectification product, maintaining the temperature within said other zone such as to effect substantially complete removal of carbon dioxide from the expanded air and from the said stream consisting of the remainder of the air passed through said other zone, periodically reversing the flow of expanded air and one of the rectification product streams through their respective paths in said other zone, and periodically reversing the flow of the stream consisting of the remainder of the air and the other of said rectification product streams through their respective paths in said other zone, whereby upon each of said reversals the rectification product streams substantially completely remove the carbon dioxide deposited in said other zone during the preceding step of the process.

2. In a process for producing oxygen by the liquefaction and rectification of air, the steps which comprise passing a stream of air under pressure through a path in a heat exchange zone, passing a stream of rectification product through another path in said heat exchange zone in heat exchange relation with the air passing therethrough to cool said air stream, expanding a minor portion of the thus cooled air stream, passing the expanded air through a path in another heat exchange zone, passing through paths in said other heat exchange zone in heat exchange relation with said expanded air a stream consisting of the remainder of the air and at least two streams of rectification product, maintaining the temperature within said other zone such as to effect substantially complete removal of carbon dioxide from the expanded air and from the said stream consisting of the remainder of the air passed through said other zone, maintaining the temperature difference between the temperature of the air leaving and the weighted average temperature of the rectification products entering said other zone within the range of 5° to 10° F., periodically reversing the flow of expanded air and the said one of said rectification product streams through their respective paths in said other zone, and periodically reversing the flow of the stream consisting of the remainder of the air and the said other of said rectification product streams through their respective paths in said other zone, whereby upon each of said reversals the rectification product streams substantially completely remove the carbon dioxide deposited in said other zone during the preceding step of the process.

3. In a process for producing oxygen by the liquefaction and rectification of air, the steps which comprise passing a stream of air under pressure through a path in a heat exchange zone, passing a stream of rectification product through another path in said heat exchange zone in heat exchange relation with the air passing therethrough, expanding a minor portion of the air stream, passing the stream consisting of the remainder of the air through a path in a second heat exchange zone, passing a stream of rectification produce through another path in said second heat exchange zone in heat exchange relation with the air, passing the expanded air stream through a path in a third heat exchange zone, passing through paths in said third heat exchange zone in heat exchange relation with said expanded air a stream consisting of the remainder of the air and at least two streams of rectication product through another path in said sec- within said third zone such as to effect substantially complete removal of carbon dioxide from the expanded air and from the stream consisting of the remainder of the air passed through said third zone, maintaining the temperature difference between the temperature of the air leaving and the weighted average temperature of the rectification products entering said third zone within the range of 5° to 10° F., periodically reversing the flow of expanded air and the said one of said rectification product streams through their respective paths in said third zone, and periodically reversing the flow of the stream consisting of the remainder of the air and the said other of said rectification product streams through their respective paths in said third zone, whereby upon each of said reversals the rectification product stream substantially completely removes the carbon dioxide deposited in said third zone during the preceding step of the process.

4. In a process for producing oxygen by the liquefaction and rectification of air, the steps which comprise passing a stream of air under pressure through a path in a heat exchange zone, passing streams of oxygen and nitrogen rectification products through other paths in said heat exchange zone in heat exchange relation with the air passing therethrough, expanding a minor portion of the air stream leaving said heat exchange zone, passing the expanded air through a path in another heat exchange zone, passing through paths in said other heat exchange zone in heat exchange relation with said expanded air stream a stream consisting of the remainder of the air, and nitrogen and oxygen rectification product streams, maintaining the temperature within said other zone such as to effect substantially complete removal of carbon dioxide from the expanded air and the stream consisting of the remainder of the air passed through said other zone, maintaining the temperature difference between the temperature of the air leaving and the weighted average temperature of the oxygen and nitrogen rectification products entering said other zone within the range of 5° to 10° F., periodically reversing the flow of expanded air and the oxygen rectification product stream through their respective paths in said other zone, and periodically reversing the flow of the stream consisting of the remainder of the air and the said nitrogen

rectification product stream through their respective paths in said other zone, whereby upon each of said reversals the rectification product streams substantially completely remove the carbon dioxide deposited in said other zone during the preceding step of the process.

5. In a process for producing oxygen by the liquefaction and rectification of air, the steps which comprise passing a stream of air under pressure through a path in a heat exchange zone, passing streams of oxygen and nitrogen rectification products through other paths in said heat exchange zone in heat exchange relation with the air passing therethrough, expanding a minor portion of the air stream leaving said heat exchange zone, passing the expanded air through a path in another heat exchange zone, passing through paths in said other heat exchange zone in heat exchange relation with said expanded air stream a stream consisting of the remainder of the air, a nitrogen rectification product stream and a plurality of oxygen rectification product streams, maintaining the temperature within said other zone such as to effect substantially complete removal of carbon dioxide from the expanded air and the stream consisting of the remainder of the air passed through said other zone, maintaining the temperature difference between the temperature of the air leaving and the weighted average temperature of the oxygen and nitrogen rectification products entering said other zone within the range of 5° to 10° F., periodically reversing the flow of expanded air and one of said oxygen rectification product streams through their respective paths in said other zone, the air stream during each succeeding reversal flowing through a different oxygen rectification product path, and periodically reversing the flow of the stream consisting of the remainder of the air and the nitrogen rectification product stream through their respective paths in said other zone, whereby upon each of said reversals the rectification product streams substantially completely remove the carbon dioxide deposited in said other zone during the preceding step of the process.

6. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing a stream of air at a pressure of from about 60 to about 100 pounds and a temperature of from about 70° to about 110° F. through a path in a first heat exchange zone, passing through two other paths in said heat exchange zone streams of oxygen and nitrogen rectification products in heat exchange relation with the air, expanding a minor portion of the air thus cooled to a pressure of from about 4 to about 10 pounds, passing the expanded air through a path in another heat exchange zone, passing oxygen rectification product, nitrogen rectification product and a stream consisting of the remainder of the air at a pressure of from about 60 to about 100 pounds through their respective paths in said other heat exchange zone in heat exchange relation with each other, maintaining the temperature in said other heat exchange zone such that substantially all carbon dioxide contained in the air streams passing therethrough is removed from the air streams during their flow through their respective paths in said other heat exchange zone, periodically reversing the flow of the oxygen and expanded air streams through their respective paths in said other heat exchange zone, periodically reversing the flow of nitrogen rectification product and the stream consisting of the remainder of the air through their respective paths in said other heat exchange zone, whereby upon each of said reversals the oxygen and nitrogen rectification products substantially completely remove the carbon dioxide deposited in the paths of flow in said other zone through which the expanded air and the remainder of the air passed during the preceding step of the process, and passing the stream consisting of the remainder of the air to the high pressure stage of a two-stage rectification system and the expanded air to the low pressure stage of said rectification system.

7. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing a stream of air at a pressure of from about 60 to about 100 pounds and a temperature of from about 70° to about 110° F. through a path in a first heat exchange zone, passing through two other paths in said heat exchange zone streams of oxygen and nitrogen rectification products in heat exchange relation with the air, expanding a minor portion of the air thus cooled to a pressure of about 4 to 10 pounds, passing a stream consisting of the remainder of the air through a path in a second heat exchange zone, passing streams of oxygen and nitrogen rectification products through other paths in said second heat exchange zone in heat exchange relation with the air, passing the expanded air through a path in a third heat exchange zone, passing oxygen rectification product, nitrogen rectification product and a stream consisting of the remainder of the air through their respective paths in said third heat exchange zone in heat exchange relation with each other, maintaining the temperature in said third heat exchange zone such that substantially all carbon dioxide contained in the air streams passing therethrough is removed from these air streams during their flow through their respective paths in said third heat exchange zone, periodically reversing the flow of the oxygen and expanded air streams through their respective paths in said third heat exchange zone, periodically reversing the flow of nitrogen rectification product and the stream consisting of the remainder of the air through their respective paths in said third heat exchange zone, whereby upon each of said reversals the oxygen and nitrogen rectification products respectively substantially completely remove the carbon dioxide deposited in the paths in said third zone through which the expanded air and the remainder of the air passed during the preceding step of the process, and passing the stream consisting of the remainder of the air to the high pressure stage of a two-stage rectification system and the expanded air to the low pressure stage of said rectification system.

8. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing a stream of air at a pressure of from about 60 to about 100 pounds and a temperature of from about 70° to about 110° F. through a path in a first heat exchange zone, passing through two other paths in said heat exchange zone streams of oxygen and nitrogen rectification products in heat exchange relation with the air, expanding a minor portion of the air thus cooled to a pressure of from about 4 to about 10 pounds, passing a stream consisting of the remainder of the air through a path in a second heat exchange zone, passing streams of oxygen and nitrogen rectification products through other paths in said second heat exchange zone in heat exchange relation with the air, passing the expanded air through a path in a third heat exchange zone,

passing a plurality of streams of oxygen rectification product, a stream of nitrogen rectification product and a stream consisting of the remainder of the air leaving said second heat exchange zone through their respective paths in said third heat exchange zone in heat exchange relation with each other, maintaining the temperature in said third heat exchange zone such that substantially all carbon dioxide contained in the air streams passing therethrough is removed from these air streams during their flow through their respective paths in said third heat exchange zone, periodically reversing the flow of one of the oxygen and expanded air streams through their respective paths in said third heat exchange zone, the expanded air stream upon each succeeding reversal flowing through a different oxygen rectification product path, periodically reversing the flow of nitrogen rectification product and the stream consisting of the remainder of the air through their respective paths in said third heat exchange zone, whereby upon each of said reversals the oxygen and nitrogen rectification products respectively substantially completely remove carbon dioxide deposited in the paths in said third zone through which passed the expanded air and the stream consisting of the remainder of the air during the preceding step of the process, and passing the stream consisting of the remainder of the air to the high pressure stage of a two-stage rectification system and the expanded air to the low pressure stage of said rectification system.

9. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing a stream of air through a path in a heat exchange zone containing at least three paths in heat exchange relation with each other, passing respectively streams of oxygen and nitrogen products of rectification through the other paths in said zone in heat exchange relation with the air passing therethrough, thereby cooling the air to a temperature such that substantially all moisture is removed therefrom, expanding a minor portion of the air leaving said first zone, passing the remainder of the air from the first zone through a path in a second zone in heat exchange relation with streams of oxygen and nitrogen products of rectification passing through their respective paths in said second zone, passing the air stream leaving said second zone through a path in a third zone in heat exchange relation with streams of oxygen and nitrogen products of rectification and the expanded air stream passing through their respective paths in said third zone, maintaining temperature conditions within said second and third zones such as to effect substantially no condensation of condensible constituents from the air in its passage through said second zone and the substantially complete removal of carbon dioxide from the air in its passage through said third zone, periodically reversing the flow of air and nitrogen through their respective paths in the first and third zones, the air upon reversal flowing through the paths through which had previously flowed the nitrogen and the nitrogen flowing through the paths through which had previously flowed the air, periodically reversing the flow of the expanded air and oxygen through their respective paths in the third zone, the air upon reversal flowing through the path through which had previously flowed the oxygen and the oxygen flowing through the path through which had previously flowed the air, whereby upon each reversal the nitrogen and oxygen substantially completely remove the carbon dioxide deposited in said third zone during the preceding step of the process, and passing the expanded air to the low pressure stage of a two-stage rectification system and the remainder of the air to the high pressure stage of said rectification system.

10. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing a stream of air at a pressure of from about 60 to about 100 pounds and a temperature of from about 70° to about 110° F. through a path in a heat exchange zone containing at least three paths in heat exchange relation with each other, passing respectively streams of oxygen and nitrogen products of rectification through the other paths in said zone in heat exchange relation with the air passing therethrough, expanding a minor portion of the air leaving said first zone to a pressure of from about 4 to about 10 pounds, passing the remainder of the air from the first zone through a path in a second zone in heat exchange relation with streams of oxygen and nitrogen products of rectification passing through their respective paths in said second zone, passing the air stream leaving said second zone through a path in a third zone in heat exchange relation with streams of oxygen and nitrogen products of rectification and the expanded air stream passing through their respective paths in said third zone thereby cooling the expanded air and the stream consisting of the remainder of the air to a temperature of from about −260° to about −280° F. and effecting substantially complete removal of carbon dioxide from the air in its passage through said third zone, periodically reversing the flow of air and nitrogen through their respective paths in the first zone and the flow of said stream consisting of the remainder of the air and nitrogen through their respective paths in said third zone, the air upon reversal flowing through the paths through which had previously flowed the nitrogen and the nitrogen flowing through the paths through which had previously flowed the air, periodically reversing the flow of the expanded air and oxygen through their respective paths in said third zone, the air upon reversal flowing through a path through which had previously flowed the oxygen and the oxygen flowing through a path through which had previously flowed the air, whereby upon each reversal the nitrogen and oxygen substantially completely remove the carbon dioxide deposited in said third zone during the preceding step of the process, and passing the expanded air to the low pressure stage of a two-stage rectification system and the remainder of the air to the high pressure stage of said rectification system.

11. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing a stream of air through a path in a heat exchange zone containing at least three paths in heat exchange relation with each other, passing respectively streams of oxygen and nitrogen products of rectification through the other paths in said zone in heat exchange relation with the air passing therethrough, thereby cooling the air to a temperature such that substantially all moisture is removed therefrom, expanding a minor portion of the air leaving said first zone, passing the remainder of the air from the first zone through a path in a second zone in heat exchange relation with streams of oxygen and nitrogen products of rectification passing through their respective paths in said second zone, passing the air stream leaving said second zone

through a path in the third zone in heat exchange relation with a stream of nitrogen product of rectification, a plurality of streams of oxygen product of rectification and the expanded air stream passing through their respective paths in said third zone, maintaining temperature conditions within said second and third zones such as to effect substantially no condensation of condensible constituents from the air in its passage through said second zone and the substantially complete removal of carbon dioxide from the air in its passage through said third zone, periodically reversing the flow of air and nitrogen through their respective paths in the first zone and the flow of the said stream consisting of the remainder of the air and nitrogen through their respective paths in the third zone, the air upon reversal flowing through the paths through which had previously flowed the nitrogen and the nitrogen flowing through the paths through which had previously flowed the air, periodically reversing the flow of the expanded air and one of said oxygen streams through their respective paths in the third zone, the air stream upon each succeeding reversal flowing through a different oxygen rectification product path, the air upon reversal flowing through a path through which had previously flowed the oxygen and the oxygen flowing through a path through which had previously flowed the air, whereby upon each reversal the nitrogen and oxygen substantially completely remove the carbon dioxide deposited in said third zone during the preceding step of the process, and passing the expanded air to the low pressure stage of a two-stage rectification system and the remainder of the air to the high pressure stage of said rectification system.

12. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing air under pressure through a path in a heat exchange zone containing three paths in heat exchange relation with each other, flowing oxygen and nitrogen products of rectification respectively through the other two paths in said zone in heat exchange relation with the air, expanding a minor portion of the air leaving the first zone, passing the remainder of the air through a path in a second zone in heat exchange relation with the oxygen and nitrogen products of rectification, thereafter passing the remainder of the air through a path in a third zone in heat exchange relation with (*a*) three streams of oxygen rectification product, (*b*) a stream of nitrogen rectification product, and (*c*) a stream consisting of the expanded air, maintaining the differential between the temperature of the air and the weighted average temperature of the nitrogen and oxygen at the colder end of said third zone within the range of about 5° to about 10° F., whereby complete removal of carbon dioxide from both streams of air passing through said third zone takes place, passing the remainder of the air from the third zone to the high pressure stage of a two-stage rectification system, passing the expanded air stream from the third zone to the low pressure stage of said two-stage rectification system, withdrawing from the high pressure stage about 1% to about 15% of the total nitrogen introduced into the process, said nitrogen containing incondensible gases, expanding said nitrogen stream, passing the expanded nitrogen in heat exchange relation with oxygen and nitrogen supplied as reflux to the low pressure stage and with the air supplied to the high pressure stage, periodically reversing the flow of air and nitrogen through their respective paths in the first zone, periodically reversing the flow of the said remainder of the air and nitrogen through their respective paths in the third zone, periodically reversing the flow of the expanded air and one of said three streams of oxygen flowing through said third zone, the expanded air upon each succeeding reversal flowing through a different one of the three oxygen paths in said third zone, said last-mentioned reversal being effected so that oxygen flows through each of the oxygen flow paths for a period three times as long as the flow of air therethrough, whereby upon each reversal the nitrogen substantially completely removes the carbon dioxide deposited in the path in said third zone through which the remainder of the air flowed during the preceding step of the process and the oxygen substantially completely removes the carbon dioxide deposited in the path in said third zone through which the expanded air flowed during the preceding step of the process.

13. A process for producing oxygen by the liquefaction and rectification of air which comprises passing air at about 60 to about 100 pounds and a temperature of about 70° to about 110° F. through a path in a heat exchange zone containing three paths in heat exchange relation with each other, flowing oxygen and nitrogen products of rectification respectively through the other two paths in said zone in heat exchange relation with the air, the air thus being cooled to a temperature such that moisture is removed therefrom, expanding from about 5% to about 10% of the air leaving the first zone to a pressure of about 4 to 10 pounds, passing the remainder of the air through a path in a second zone in heat exchange relation with the oxygen and nitrogen products of rectification, thereby cooling the air to a temperature of about —180° to about —210° F., thereafter passing the remainder of the air through a path in a third zone in heat exchange relation with (*a*) three streams of oxygen rectification product, (*b*) a stream of nitrogen rectification product, and (*c*) a stream consisting of the expanded air, thereby cooling the remainder of the air to a temperature of about —260° to about —280° F., maintaining the differential between the temperature of the air and the weighted average temperature of the oxygen and nitrogen at the colder end of said third zone within the range of about 5° to about 10° F., passing the remainder of the air from the third zone to the high pressure stage of a two-stage rectification system, passing the expanded air from the third zone to the low pressure stage of said two-stage rectification system, withdrawing from the high pressure stage about 1% of about 15% of the total nitrogen introduced into the process, said nitrogen containing incondensible gases, expanding said nitrogen stream, passing the expanded nitrogen in heat exchange relation with oxygen and nitrogen supplied as reflux to said low pressure stage and with the air supplied to the high pressure stage, periodically reversing the flow of air and nitrogen through their respective paths in the first zone, periodically reversing the flow of the said remainder of the air and nitrogen through their respective paths in the third zone, periodically reversing the flow of the expanded air and one of said three streams of oxygen flowing through said third zone, the expanded air upon each succeeding reversal flowing through a different one of the three oxygen paths in said third zone, said last-mentioned reversal being effected so that oxygen

flows through each of the oxygen flow paths for a period three times as long as the flow of air therethrough, whereby upon each reversal the nitrogen substantially completely removes the carbon dioxide deposited in the path in said third zone through which the stream consisting of the remainder of the air flowed during the preceding step of the process and the oxygen substantially completely removes the carbon dioxide deposited in the path in said third zone through which the expanded air flowed during the preceding step of the process.

14. A process for producing oxygen by the liquefaction and rectification of air which comprises passing air at about 60 to about 100 pounds and a temperature of about 70° to about 110° F. through a path in a heat exchange zone containing three paths in heat exchange relation with each other, flowing oxygen and nitrogen products of rectification respectively through the other two paths in said zone in heat exchange relation with the air, the air thus being cooled to a temperature such that moisture is removed therefrom, expanding from about 5% to about 10% of the air leaving the first zone to a pressure of about 4 to 10 pounds, passing the remainder of the air through a path in a second zone in heat exchange relation with the oxygen and nitrogen products of rectification, thereby cooling the air to a temperature of about −180° to about −210° F., thereafter passing the air through a path in a third zone in heat exchange relation with (*a*) three streams of oxygen rectification product, (*b*) a stream of nitrogen rectification product, and (*c*) a stream consisting of the expanded air, thereby cooling the remainder of the air to a temperature of about −260° to about −280° F., maintaining the differential between the temperature of the air and the weighted average temperature of the oxygen and nitrogen at the colder end of said third zone within the range of about 5° to about 10° F., passing the remainder of the air from the third zone through the high pressure stage of a two-stage rectification system, passing the expanded air from the third zone to the low pressure stage of said two-stage rectification system, withdrawing from the high pressure stage about 1% to 15% of the total nitrogen introduced into the process, said nitrogen containing incondensible gases, heating approximately 10% of the nitrogen thus withdrawn, mixing the heated nitrogen with the remaining 90% of the nitrogen thus withdrawn, thereby yielding a nitrogen stream having a temperature sufficiently high to avoid the formation of liquid nitrogen upon expansion of the nitrogen stream, expanding said nitrogen stream, passing the expanded nitrogen in heat exchange relation with oxygen and nitrogen supplied as reflux to the low pressure stage and with the air supplied to the high pressure stage, periodically reversing the flow of air and nitrogen through their respective paths in the first zone, periodically reversing the flow of the said remainder of the air and nitrogen through their respective paths in the third zone, periodically reversing the flow of the expanded air and one of said three streams of oxygen flowing through said third zone, the expanded air upon each succeeding reversal flowing through a different one of the three oxygen paths in said third zone, said last-mentioned reversal being effected so that oxygen flows through each of the oxygen flow paths for a period three times as long as the flow of air therethrough, whereby upon each reversal the nitrogen substantially completely removes the carbon dioxide deposited in the path in said third zone through which the remainder of the air flowed during the preceding step of the process and the oxygen substantially completely removes the carbon dioxide deposited in the path in said third zone through which the expanded air flowed during the preceding step of the process.

15. A process for producing oxygen by the liquefaction and rectification of air, which comprises passing a stream of oxygen rectification product through a path in a first and second heat exchange zone in series, passing a stream of nitrogen rectification product through a path in a third and fourth heat exchange zone arranged in series relative to each other and in parallel relative to the said first and second heat exchange zones, passing in heat exchange relation with the oxygen flowing through its path in the first heat exchange zone a stream of air under pressure, expanding the air stream leaving its flow path in said first heat exchange zone, passing a stream of air under pressure through a path in the third heat exchange zone, dividing the air leaving its path in said third heat exchange zone into two streams and passing the resultant streams through paths in the second and fourth heat exchange zones in indirect heat exchange relation with the oxygen flowing through said second heat exchange zone and the nitrogen flowing through the fourth heat exchange zone, passing the expanded air through a flow path in a fifth heat exchange zone, passing a plurality of streams of oxygen through individual paths in said fifth heat exchange zone, passing a stream of nitrogen through a path in said fifth heat exchange zone and passing a stream consisting of the air leaving the second and fourth heat exchange zones into and through a flow path in said fifth heat exchange zone, all of said flow paths in the fifth heat exchange zone being in heat exchange with each other, passing the expanded air from the fifth heat exchange zone to the low pressure stage of a two-stage rectification system, passing the other air stream passing through said fifth heat exchange zone to the high pressure stage of the said two-stage rectification system, maintaining the temperature difference between the air leaving and the weighted average temperature of the oxygen and nitrogen entering said fifth heat exchange zone within the range of 5° to 10° F., maintaining the temperature of the air exit end of said fifth heat exchange zone at a point such that the carbon dioxide is substantially completely removed from the air passing therethrough, periodically reversing the flow of air and oxygen in said first heat exchange zone, of air and nitrogen in said third heat exchange zone, of the said other air stream and nitrogen in said fifth heat exchange zone and of the expanded air and one of the oxygen streams flowing through said fifth heat exchange zone, whereby upon each of the said reversals the oxygen and nitrogen rectification products respectively substantially completely remove the carbon dioxide deposited in the paths of flow in said fifth heat exchange zone through which the expanded air and the said other air stream passed during the preceding step of the process.

16. In a process for producing oxygen by the liquefaction and rectification of air, the steps which comprise passing a stream of air under pressure through a heat exchange zone, passing a stream of rectification product through said

heat exchange zone to effect cooling of said air stream, expanding a minor portion of the thus cooled air stream, passing the expanded air through another heat exchange zone, passing the remainder of the thus cooled air through said other heat exchange zone, passing through said other heat exchange zone at least two streams of rectification product, maintaining the temperature within said other heat exchange zone such as to effect substantially complete removal of carbon dioxide from the expanded air and from the said stream consisting of the remainder of the

air passed through said other heat exchange zone, periodically reversing the flow of expanded air and one of the rectification product streams through their respective paths in said other heat exchange zone, and periodically reversing the flow of the stream consisting of the remainder of the air and the other of said rectification product streams through their respective paths in said other heat exchange zone.

EDWARD G. SCHEIBEL.

No references cited.

Certificate of Correction

Patent No. 2,504,051 April 11, 1950

EDWARD G. SCHEIBEL

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 18, line 17, for the word "produce" read *product*; line 25, strike out "through another path in said sec-" and insert instead , *maintaining the temperature*; and that the said Letters Patent should be read as corrected above, so that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 7th day of November, A. D. 1950.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.