

March 11, 1952

W. W. PAGET

2,588,656

METHOD OF AND APPARATUS FOR TREATING GASES

Filed Oct. 18, 1949

2 SHEETS—SHEET 1

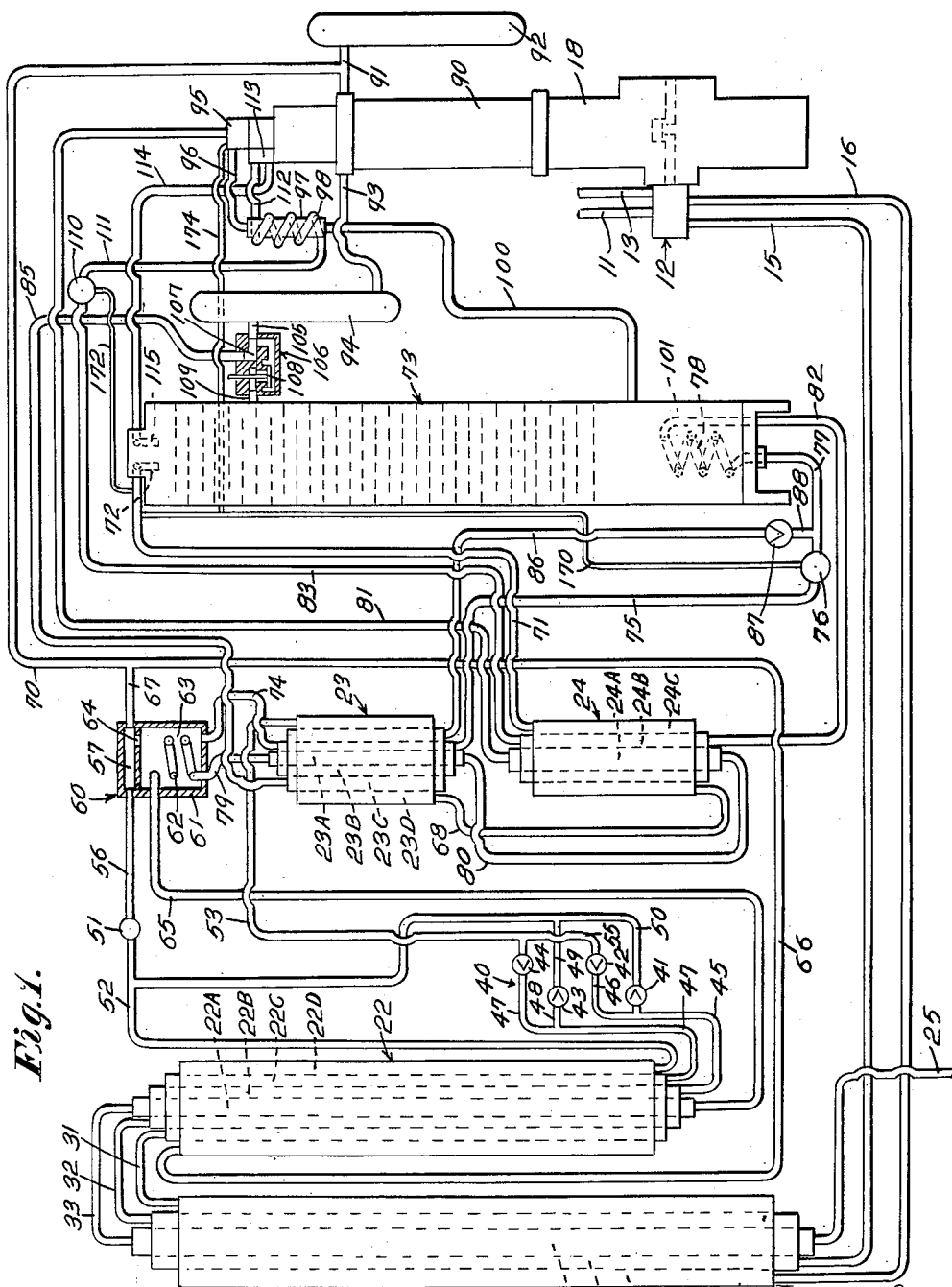


Fig. 1.

Fig. 10.

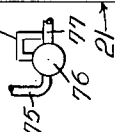
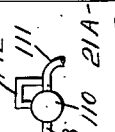


Fig. 11.



Inventor:
Win. W. Paget.
by *John F. Schmidt*
att'y.

March 11, 1952

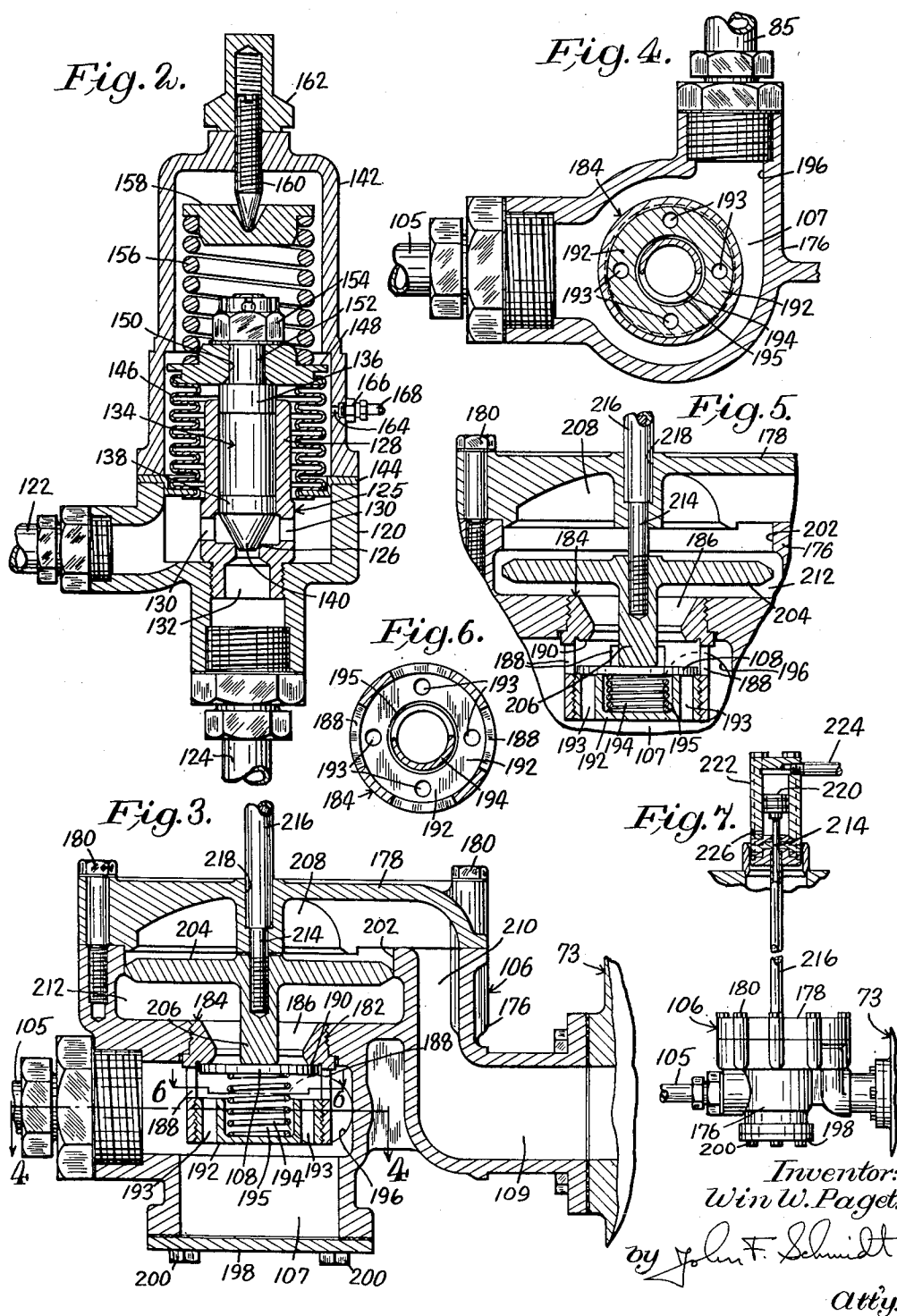
W. W. PAGET

2,588,656

METHOD OF AND APPARATUS FOR TREATING GASES

Filed Oct. 18, 1949

2 SHEETS--SHEET 2



UNITED STATES PATENT OFFICE

2,588,656

METHOD OF AND APPARATUS FOR
TREATING GASES

Win W. Paget, Michigan City, Ind., assignor to
Joy Manufacturing Company, Pittsburgh, Pa.,
a corporation of Pennsylvania

Application October 18, 1949, Serial No. 122,079

10 Claims. (Cl. 62—2)

1

This invention relates to improvements in methods of and means for treating gases; this application is a continuation-in-part of my co-pending but now abandoned application Serial No. 31,016, filed June 4, 1948.

It will herein be described particularly in its application to the production of substantially pure oxygen from air, but this is but illustrative, because the process and apparatus disclosed may be used, with appropriate adaptations, with various gases to be processed, to produce various particularly desired products which are constituents of the gases to be treated. Under some circumstances the desired product may be delivered at a relatively very high pressure and under others at a pressure of a few atmospheres.

It is commonly desirable, in the production of oxygen by a process involving cooling and rectification of compressed air, to have the oxygen available in gaseous form at a pressure substantially above column pressure but, on the other hand, much below cylinder pressure (cylinder pressure is on the order of 2000 p. s. i.). For example, oxygen may be desired at a pressure on the order of 50 p. s. i., though this is but illustrative and indeed, the reference to oxygen is but illustrative also, because other gases which may be obtained by a similar process may also be desired at pressures above column pressure. Taking the case of oxygen for purposes of illustration, refrigeration can be saved by taking gaseous rather than liquid oxygen from a point in a column above the level of the liquid oxygen therein and boosting the pressure from the few p. s. i. (perhaps 5) which exists at that point in the column, to the desired delivery pressure by the use of a compressor. However, this is objectionable because of the additional power required and because of the size of the gaseous oxygen compressor which would be required. It is much preferable to take liquid oxygen from the column and to pump it at the desired pressure to the oxygen supply line. This permits the use of much smaller pumping equipment. It would, however, result in wasted refrigeration if some provision were not made for using the heat of vaporization of liquid oxygen in some manner.

As is disclosed and claimed in the application of Samuel C. Collins, Serial No. 122,077 filed October 18, 1949, this heat of vaporization may be utilized by condensing an "equivalent" amount of air on its way to the rectifier, as by bringing an appropriate amount of air at an appropriate pressure and temperature into heat exchange relation with the leaving oxygen at a pressure

2

substantially above column pressure, and utilizing the heat of vaporization to effect the liquefaction of compressed air.

I have found that efficient apparatus which is substantially automatic may be made for the production of substantially pure oxygen in accordance with the foregoing, by the provision in the apparatus of valves which are responsive to pressure at selected points in the system. As is set forth in detail below, two different embodiments of the invention are shown herein, both of which are self-regulating to operate the system at a substantially constant compressed air supply pressure regardless of variations in the demand for oxygen.

In one of the embodiments, the two expansion valves, which are in series, are arranged so that each valve opens at a predetermined upstream pressure above a given "reference pressure" of the system, the reference pressure being preferably column pressure. In another embodiment, each valve is arranged to maintain a predetermined pressure differential between its inlet and discharge sides. In both embodiments, the pressure responsive control valves serve to maintain a substantially constant back-pressure on the compressed air supply line, obviating the necessity of pressure relief valves, which are wasteful of power.

Apart from the feature of maintaining a constant back pressure on the compressor, this invention makes the oxygen production apparatus and method completely self-regulating, notwithstanding variations in the demand for oxygen and, in fact, in accordance with varying demands. Thus the valve structures provided in this invention automatically adjust fluid flow to accord with changed conditions in various parts of the system occasioned by shifts in the system between 2000-pound oxygen production and 50-pound production.

In addition to pressure responsive expansion valves, the invention includes a so-called "by-pass" valve which is arranged to respond to demands on the system to by-pass the expansion engine exhaust around one of the expansion valves directly into the column at the same time that admission valve cutoff is shortened, this occurring automatically when the apparatus shifts from production of oxygen at 50 pounds to production at 2000 pounds. The reverse change is automatically made upon shift the other way.

The by-pass valve construction is such as to protect the column against damage from blast which might occur if the relatively high pressure

3

engine exhaust, at 50 pound oxygen production, were suddenly released into the comparatively low pressure column.

It is thus among the objects of the invention to provide a simple, compact, flexible apparatus for the efficient separation of gases, in which oxygen can be supplied in accordance with requirements by a system embodying valves which make the system self-regulating by quickly responding to pressure changes at predetermined points in the system as variations in the demand for oxygen alter the fluid flow and pressure in the different parts of the apparatus; and in which a predetermined back pressure is maintained on the compressed air supply source regardless of demands on the system for gas. It is a further object of the invention to provide control valves which respond to pressure changes at selected points of the system to maintain desired flow and pressure balances, and which effect the desired control without damage to the system itself.

In the obtaining of oxygen by a process involving cooling and rectification of compressed air (oxygen is again used here merely as illustrative of other gases which may be obtained by such a type of process), air is supplied at a desired initial pressure, cooled, condensed and rectified, and the end product is delivered for use, and the pressure at which the air is supplied is desirably maintained within very close limits throughout the entire period of processing after the apparatus has once been brought to the desired working conditions.

The aforesaid and other objects are achieved in the invention described hereinafter, in which the maintenance of the desired uniformity of air supply pressure is obtained by adapting the size of the compressor closely to the capacity of the oxygen generator, and by employing two pressure controlling valves arranged in series, each valve being set to open at a predetermined pressure of the supply fluid above the operating pressure of the system at a selected point, the pressure at that point being known as the "reference pressure." Alternatively, each valve can be arranged to give a predetermined pressure drop between the upstream and downstream sides thereof. One valve is disposed between the air source and an evaporator-condenser in the column, and the other between the evaporator-condenser and a point at the top of the column to which liquid air is to be delivered. The invention is shown as applied to a single column system, but a person skilled in the art will be able to apply it to other systems, as for example to the double column systems shown in patent application Serial No. 122,077 filed October 18, 1949 and assigned to the assignee of this invention, in which the single and double-column systems are disclosed as embodying manually adjustable valves.

It will be found in the explanation below that the second valve in effect maintains a predetermined substantially constant pressure drop between its supply and discharge sides, even in the embodiment shown in Fig. 1, because of the proximity of the valve to that point of the system which provides the "reference pressure." The characteristics of the columns require, at least in some cases, that the second valve provide a pressure drop between its opposite sides of slightly more than 60 p. s. i., in order that condensation of gaseous air in the column shall take place at a sufficiently high temperature to effect evaporation of oxygen at the pressure prevailing in the column. (The column pressure, for all practical purposes, is the "reference pressure" referred to

4

above.) The other of the two valves is designed to maintain such an air supply pressure as may be consistent with sound compressor design. In one embodiment of the invention, the valve provides an upstream pressure which, when added to the pressure required to overcome friction losses in the apparatus to that point, will require compressed air to be supplied to the system at 160 p. s. i. for a column pressure of 7 p. s. i. (all pressures are gauge unless otherwise indicated). In the other embodiment, said other valve is arranged to provide a pressure differential between its supply and discharge sides such that the total pressure drop through the system equals the desired air supply pressure.

In apparatus like that hereinafter described, oxygen may be produced at 40 to 50 p. s. i. or at a much higher value suited to charging cylinders. When making oxygen at the lower pressure, the reduction in pressure across the expansion engine is equal to that across the valve which is arranged in the line between the evaporator-condenser and the point of induction of compressed air from the evaporator-condenser to the column. When charging cylinders, substantially the entire pressure drop from supply to column pressure is taken by the expansion engine, except for pressure required to overcome friction losses in the system to the point of air intake for the engine. It may be pointed out here that friction losses in the system are usually treated herein as being negligible.

In the accompanying drawings,

Figure 1 is a diagrammatic view of a single column embodiment of the invention;

Figures 1a and 1b show details of the system for another embodiment of the invention;

Figure 2 is a longitudinal section through one of the pressure control valves;

Figure 3 is a longitudinal section through the by-pass valve;

Figure 4 is a view in section on the plane of line 4-4 of Figure 3;

Figure 5 is a partial view, similar to that of Figure 3, but showing the valve in its open position;

Figure 6 is a view in section on the plane of line 6-6 of Figure 3; and

Figure 7 is a view, with parts broken away and in section, of the by-pass valve and its associated control.

Referring first to the system, air at a temperature of approximately 300° K. and a pressure of 160 p. s. i. may be delivered, as from a suitable air compressor (not shown) through a conduit 11 to a valve mechanism generally designated 12, and the effluent (mainly nitrogen) leaving the apparatus may be discharged to the atmosphere through a conduit 13. The valve mechanism 12 is of the mechanically actuated type, and is periodically moved by power, and with a snap action, to reverse the connections of the conduits 11 and 13 with a pair of conduits 15 and 16 which lead from the casing of the valve mechanism 12. In the Samuel C. Collins application Serial No. 661,253, filed April 11, 1946, there is diagrammatically shown a reversing valve mechanism suitable for the performance of the functions of the valve mechanism 12; and another example of a mechanism suitable for this purpose is shown in an application of Win W. Paget, Serial No. 35,092, filed June 25, 1948.

The power to shift valve mechanism 12 to alternately connect air conduit 11 with conduits

15 and 16, and simultaneously alternately connect conduit 13 with conduits 16 and 15 may be taken from any suitable source, but is desirably taken from the drive shaft of an expansion engine 18, through any suitable reducing gearing such as that shown diagrammatically in said Collins application, Serial No. 661,253. Reversals are adapted to be effected at relatively short intervals; and suitable intervals may be on the order of three minutes.

Heat exchangers 21 and 22, desirably vertically disposed and formed as separate units instead of as one longer unit, in order to keep height within desirable limits, are arranged in series, and entering air passes through the heat exchangers 21 and 22 in the order mentioned, while leaving nitrogen passes through these same heat exchangers in the order 22, 21. Heat exchanger 21 has three courses, indicated as coaxial courses 21A, 21B and 21C, the first the innermost course and the latter the outermost; and exchanger 22 has similarly relatively arranged courses 22A, 22B and 22C, and, outside 22C, a fourth course 22D.

Through two of the courses in series in the exchangers 21 and 22, to wit, courses 21B, 22B and courses 21C, 22C, the entering air and the leaving nitrogen flow alternately, the entering air flowing inward through one or the other of these pairs of courses and the nitrogen flowing outward through the one of such pairs of courses not at any given moment serving for the inflow of the air. Through the third course, 21A, of the exchanger 21 and through the corresponding course, 22A, of the exchanger 22, but in the order 22A, 21A, the leaving oxygen product is discharged. Exchanger 22 has, as above noted, a fourth course 22D, through which a portion of the air which is entering the apparatus by way of the exchangers 21, 22 is caused to recirculate through exchanger 22, the better to effect deposition of impurities from the entering air stream and to increase the temperature of the air entering the expansion engine.

It has been noted, with respect to the exchangers 21 and 22, and, it will be noted, with respect to further heat exchangers 23 and 24 hereinafter to be described, that the courses are indicated as being coaxial. It will, however, be appreciated that the precise form of construction of the exchangers is not illustrated in the diagram of Fig. 1, since suitable multiple pass exchangers may assume various forms, and, in the Samuel C. Collins application above identified, a suitable form of exchanger is illustrated, and other possible types are illustrated in other applications of said Samuel C. Collins, Serial Nos. 3,217, filed January 20, 1948, and 2,877, filed January 17, 1948. Exchanger 23 will be observed shortly to be of the four-course type, and exchanger 24 of the three-course type.

Conduit 15 communicates with course 21B of exchanger 21, and conduit 16 with course 21C of exchanger 21. The leaving oxygen product passes outward through course 21A of exchanger 21 and passes to a shop line, to a bank of cylinders, or to any other desired point or apparatus, for use or storage, through a conduit 25. Course 21C of exchanger 21 is connected by a conduit 31 with course 22C of exchanger 22. Course 21B of exchanger 21 is connected by a conduit 32 with course 22B of exchanger 22. A conduit 33 connects course 21A of exchanger 21 with course 22A of exchanger 22. These courses are traversed serially, in the order 22A, 21A, by the oxygen

product, as later described. It will be appreciated that air will flow alternately in through course 21C, conduit 31 and course 22C or course 21B; conduit 32 and course 22B, while concurrently nitrogen will flow outward through the ones of said courses and passages last mentioned not carrying the entering air.

A suitable automatic reversing valve mechanism, generally designated 40, is provided at the end of heat exchanger 22 last left by the entering air and first entered by the leaving nitrogen, this including four automatic check valves 41, 42, 43 and 44. This arrangement is disclosed in the Samuel C. Collins application Serial No. 661,253. The lower end of course 22B has connected with it a conduit 45 which leads to the check valve 41, and a branch 46 leads from conduit 45 to check valve 42. A conduit 47 leads from course 22C to check valve 44, and a branch 48 connects conduit 47, at a point between course 22C and the check valve 44, with the check valve 43. A conduit 49 connects the other side of check valve 43 with a conduit 50 leading from the check valve 41 to a suitable restrictor device 51, which creates a slight difference between the pressure in the conduit 50 and the pressure beyond the device 51, the latter pressure being on the order of two pounds less than the pressure in conduit 50. A conduit 52 connects the conduit 50 with the bottom of course 22D. A conduit 53 leads from the side of check valve 44 opposite the conduit 47, to the outermost course of the heat exchanger 23. Nitrogen always flows outward through conduit 53. A conduit 55 connects the side of check valve 42 opposite the conduit 46 to the conduit 53. Each of the check valves 41, 42, 43 and 44 opens in the direction indicated by its > and prevents opposite flow.

The restrictor 51 is connected as at 56' to a chamber 57 within the top of an evaporator-condenser 60 having a suitably insulated casing 61 and having in the casing an oxygen conducting conduit or course 62 and an air conducting conduit or course 63 in close heat exchange relation with each other. The conduit or course 63 is connected at 64 with the chamber 57. The oxygen conduit or course 62 is connected by a conduit 65 with the bottom of course 22A of exchanger 22. The top of course 22D of exchanger 22 is connected by a conduit 66 with a conduit 67 leading from the chamber 57, and the reunited stream of air passes to a conduit 70, which leads to the expansion engine 18 later more fully described.

When the air entering the system is passing through course 22B, it flows through the check valve 41. When course 22B is serving for outflow of nitrogen, the nitrogen flows from conduit 53, through conduit 55 and check valve 42 and through conduits 46 and 45 to course 22B. When course 22C is serving for inflow of air, the entering air flows through the check valve 43. When course 22C is being used to conduct leaving nitrogen, the nitrogen flows through check valve 44 and conduit 47. As the entering air is at a much higher pressure than the leaving nitrogen, no check valve subjected on its discharge side to air can be opened by the lower nitrogen pressure.

The heat exchangers 23 and 24 have been previously mentioned. Exchanger 23 has four courses: a central one, 23A, a next course 23B, a third course 23C, and an outer course 23D surrounding, as shown on the drawings, course 23C. Obviously the arrangements of the courses, and

the structure of this exchanger, are subject to wide structural variations. Exchanger 24 has a central course 24A, an outer course 24C and an intermediate course 24B. It too is subject to wide structural variation. It will be understood that the several courses will be in good heat exchange relation with respect to each other.

It has been noted that the conduit 53 is connected with the outermost course 23D of exchanger 23. This connection is with the top of such course. The bottom of course 23D is connected by a conduit 63 with the bottom of course 24C of exchanger 24, and the top of course 24C is connected by a conduit 71 with the nitrogen outlet (the efflux connection) 72 of a single column 73. The compressed air course 63 of evaporator-condenser 60 is connected by a conduit 74 with the top of course 23B of exchanger 23. The bottom of said course is connected by a conduit 75 with a suitable pressure reducing valve device 76, which is adapted, in the particular apparatus shown, and when the latter is used for oxygen production, to open at such a pressure above the reference pressure as to require compressed air to be supplied to line 11 at a pressure of 160 p. s. i. when the reference pressure is 7 p. s. i. The resulting pressure drop through valve 76 is substantially the same reduction in pressure as occurs in the expansion engine later described, when the latter is operating with its longer period of admission, hereinafter fully explained.

The low pressure side of valve device 76 is connected with a conduit 77 which leads to a condenser coil or element 78 in the lower end of the column 73. The central course (as shown) 23A of exchanger 23 is connected at its top with a conduit 79 leading to the oxygen course 62 of the evaporator-condenser 60, while its bottom is connected with the bottom of central course 24A of exchanger 24 by a conduit 80. A conduit 81 leads from the top of the central course 24A. This is connected with the discharge of a liquid oxygen pump, later described. The condenser unit 78 is connected at its other end (from the conduit 77), by a conduit 82, with the intermediate course 24B of exchanger 24. The top of course 24B is connected with a conduit 83, of which more will be shortly said.

Three of the four courses of exchanger 23 have been noted. The fourth course, 23C, is connected at its top with an expanded air conduit 85, and its lower end is connected with a conduit 86, containing a check valve 87 openable towards the conduit 77; conduit 77 is connected with valve 87 by a connection 88. The check valve opens towards the conduit 77, but only when the pressure in the conduit 86 is sufficient to effect opening of check valve 87 against the pressure in conduit 77.

The expansion engine 18 may be of the construction shown in the copending Samuel C. Collins application, Ser. No. 665,206, filed April 26, 1946, provided with suitable means for predeterminedly lengthening and shortening the period of admission, or of the character of the expansion engine employing cam follower rollers one or both of which coast with a cam depending on whether early or late cutoff is desired, which expansion engine is illustrated and described in my application, Ser. No. 31,017, filed June 4, 1948. The engine includes a cylinder 90 having admission and exhaust valves, not shown, and to the admission valve of which air under pressure is admitted from the conduit 70 through a con-

duit 91 with which an "In" surge tank 92 is connected to minimize fluctuations in flow. A discharge or exhaust connection 93 leads from the expansion engine to a "Discharge" surge tank 94, which may have associated with it a strainer to catch any snow that might otherwise attain to the column while the heat exchangers 21 and 22 were not fully cooled down during the starting of the apparatus.

The expansion engine supports on the top of its cylinder a jacketed liquid oxygen pump 95 of any suitable construction, the liquid oxygen pump being for example actuated by the expansion engine piston as is the pump shown in my last above mentioned application; and it may be noted that the conduit 81 is connected with the discharge of the liquid oxygen pump 95, while this pump has a suction connection 96 leading to it from a strainer 97 which is cooled or jacketed by liquid air, the jacket herein being represented by a coil 98. To the strainer 97 a conduit 100 leads from the bottom of the column 73, the conduit 100 communicating with the condenser-unit-enclosing chamber 101 in the bottom of the column at a point at the desired liquid oxygen level in the latter.

The "Discharge" surge chamber 94 has connected with it a conduit 105 which is connected to a valve structure 106 hereinafter more fully described, which valve structure includes a passage or chamber continuously in communication with the conduit 85, and another chamber connectable through a conduit 109 directly with the interior of the column at a point spaced an appropriate distance from the top of the latter. The valve structure 106, which may be called a by-pass valve, is adapted to have the two chambers mentioned connected in communication with each other, and thus to connect the "Discharge" surge chamber 94 in free communication with the upper part of the column through the conduit 105, valve structure 106, and conduit 109. In the drawing the constant communication between the conduits 105 and 85 is indicated by the passage 107, and the communicability of the passage or chamber 107 with the conduit 109 is indicated by the valve 108.

The expansion engine 18 is provided, in the present particular apparatus, with valve gear adapted to permit the engine to operate with admission for a relatively short portion of its working stroke, or with admission for a considerably longer portion of its working stroke. When cutoff is relatively late in the working stroke, the valve structure 106 will prevent communication between the "Discharge" surge chamber 94 and the column through the conduit 109; and when communication between the "Discharge" surge chamber 94 and the column is effected by the appropriate adjustment of the valve structure 106, the expansion engine will be operated with admission for the aforesaid relatively short portion of its working stroke.

With apparatus having, during low pressure oxygen production, the temperatures and pressures hereinafter mentioned, the relatively late cutoff of the expansion engine would theoretically take place at about 70% of the working stroke; and during high pressure oxygen production the relatively early cutoff would be at theoretically on the order of 25% of the working stroke, but these percentages are only illustrative. For example, there are two factors which in practice would tend to call for later cutoff in both modes of op-

eration, namely, that it is desirable in practice to handle at least a little larger than the theoretical mass of air to insure adequate refrigeration, and, moreover, with actual apparatus, the expected temperatures and pressures are not always attained.

Various means can be provided for effecting the desired changes in period of admission, as, for example, with a cam opened admission valve as shown in the Samuel C. Collins application Serial No. 665,206, the provision of selectively operable cams with different dwells, or cams one relatively adjustable with respect to the other. See for an example Ferguson 2,221,790, patented November 19, 1940. Or cam-follower rollers one or both cooperating with a cam depending on whether early or later cutoff is desired may be employed, as in the apparatus of my expansion engine application.

Only such air will flow through the evaporator-condenser 60 as cannot pass through the expansion engine. By very precise design, during 50-pound oxygen production, complete condensation of the fraction of air passing through the air course 63 of the evaporator-condenser 60 might conceivably be effected. If more air passes through this course, however, than can be condensed by the refrigeration provided by evaporation of liquid oxygen at a pressure on the order of 50 p. s. i. in the course 62 of the evaporator-condenser 60, the excess unliquefied air will be condensed in evaporator-condenser 78, so some excess of air will logically be permitted.

The conduit 83, previously mentioned, leads to a pressure control valve 110 which is adapted, as explained below, to effect reduction on the order of 60 p. s. i. in the pressure of the fluid (liquid air) which flows through it; and the low pressure side of the pressure reducing valve 110 is connected by a conduit 111 with the jacket 98 for the strainer 97; and the top of this jacket is connected by a conduit 112 with a jacket 113 of the liquid oxygen pump 95, there being a conduit 114 leading from the jacket 113 to a connection 115 through which liquid air may be admitted to the top of the column 73.

The column 73 may be of any suitable construction, and is illustrated as of the conventional packed type. It may obviously assume various forms, and Samuel C. Collins has filed during May 1948 two applications, Serial Nos. 26,395 and 28,870, showing columns which are well adapted for the purpose for which the present column is employed.

Referring now to Fig. 2, which shows a detail of a valve of the type adapted to be used in the position of valve 76 or valve 110, the valve is shown as comprising a two-part casing or housing, the lower portion 120 being connected by any suitable means with a high-pressure inlet 122 and low-pressure outlet 124. In the case of the valve 76, the inlet 122 is the conduit 75, and the outlet 124 is conduit 77. In the case of the valve 110, inlet 122 is the conduit 83, and outlet 124 is the conduit 111. The lower portion 120 of the casing has threaded engagement with a member 125 which provides a valve seat 126 and a valve guide 128. The member 125 is ported as shown at 130 to admit fluid from the inlet, and is further provided with an exit passage 132 to pass fluid to the outlet 124.

A closure member 134 consists of a plunger having finished guide surfaces or collars 136 and 138 which cooperate with the guide member 128 to keep the plunger 134 aligned as it reciprocates

in valve-opening and closing movement. The plunger 134 is provided with a conical portion 140 at its one end which cooperates with the seat 126 to cut off communication between inlet 122 and outlet 124, and more immediately between the inlet ports 130 and the outlet passage 132.

The upper portion 142 of the housing cooperates with the lower portion 120 to hold a septum 144 tightly clamped between the two portions of the casing. The portions 120 and 142 are clamped together by any suitable means, not shown. The septum 144 is secured in fluid-tight relationship to a pressure responsive device such as the bellows member 146. At its opposite end, the bellows 146 is provided with a movable wall 148 which has an opening 150 through it to receive a stem 152 of plunger 134. The movable wall 148 is clamped between the upper face of guide collar 136 and a nut 154 which has threaded engagement with the stem 152. A spring 156 bears at one end against the movable wall 148 and is adjustably restrained at its other end by a bearing member 158, screw 160 and the combination lock nut and cap 162.

The upper portion 142 of the casing is provided with an opening 164 which has threaded engagement with a fitting 166 to which is secured a conduit 168. The conduit 168 need not be of large dimensions because there is no fluid flow through it. The function of conduit 168 is simply to transmit pressure to the outside of bellows 146. The pressure referred to is the reference pressure described above and is preferably column pressure. For convenience, the conduit 168 is merely tapped into the efflux or nitrogen outlet 71 at a point as close as may be feasible to the column. In Fig. 1 the conduit 168 is schematically indicated by a conduit 170 for valve 76 and by conduit 172 for valve 110.

For the sake of convenience, the space surrounding the expansion engine connecting rod and the liquid oxygen pump rod may be connected to the conduit 170 of the valve 76. This connection is shown schematically by the conduit 174.

In the embodiment of the invention shown in Figs. 1a and 1b, the valves are arranged to maintain a predetermined pressure differential between their upstream and downstream conduits.

To accomplish that arrangement, the conduit 168 is connected: for valve 76, to conduit 77 by conduit 170, as shown; and for valve 110, to conduit 111 by conduit 172, as shown.

It has been pointed out that the oxygen generator is adapted to produce oxygen at 50 p. s. i. or at pressures up to 2000 p. s. i. During production of 50-pound oxygen, the expansion engine operates with relatively late cutoff and the by-pass valve 108 is closed. When 2000-pound oxygen is to be the product, the by-pass valve should be open and the engine operated with early cutoff. During starting, for the first two hours or so the by-pass valve should be open and the expansion engine operated with late cutoff. Then during the final period preceding the normal production, the expansion engine should be operated with early cutoff. The by-pass valve should be allowed to remain open during this further period. When the system becomes ready to produce oxygen on a suitable basis for an extended period, the control should provide for operation either with the by-pass valve open and early cutoff or the by-pass valve closed and late cutoff, depending upon the demands of the load imposed

by the shop on the shop line, as explained in copending joint patent application Serial No. 122,078, filed October 18, 1949. These functions of normal operation can be accomplished by a shop line pressure responsive pilot valve controlling the supply of fluid alternatively to mechanism for shifting the position of the by-pass valve, and to mechanism for making the point of cutoff later in the expansion engine.

Reference is now made to the valve 106 and more particularly to Figs. 3 to 6 inclusive for the details thereof. This valve shows a lower casing or body portion 176 which is provided with a cover 178 secured thereto by any suitable means such as threaded members 180. The body portion 176 has a threaded opening 182 to receive a plug or valve seat member 184. The valve seat member 184 has a central passage 186 therethrough and a plurality of circumferential ports 188. A seat 190 is provided on the valve seat member 184 and cooperates with the valve disc 108 to cut off communication between the circumferential ports 188 and the central passage 186. The valve seat member 184 has threaded engagement with a removable spring retainer 192 which has wrench openings 193. A spring 194 is disposed in a cup-shaped recess 195 between the spring retainer 192 and the valve disc 108, as shown.

The conduit 85 of Fig. 1 communicates directly with an opening 196 in the valve body 176 (see especially Fig. 4). Opening 196 is constantly in communication with the chamber 107, which in turn is constantly in communication with the conduit 105 of Fig. 1. A cover plate 198 is removably secured to valve body 176 by means of threaded members 200 in order to provide access to the spring retainer and valve disc assembly.

Valve body 176 is provided with a cylindrical opening 202 which is from twenty to thirty thousandths greater in diameter than the diameter of the disc of a valve 204. The valve 204 is provided with a finger portion 206 which is adapted to engage the valve disc 108 to open it. A chamber 208 in the cover member 178 is in constant communication with conduit 109 through a passage 210. When the valve 204 has been moved down into position to communicate conduit 105 with the column 73 by moving valve disc 108 away from its seat (see Fig. 5), the chamber 208 is in communication with a groove 212 which forms a chamber for valve 204.

Valve 204 is threadedly engaged by a plunger or push rod 214 which is reciprocable in sleeve 216, secured in any suitable manner in opening 218 in the cover member 178. As is more readily seen in Fig. 7, sleeve 216 provides a fluid seal and protective covering for the plunger or rod 214 of piston 220. The piston 220 is reciprocable in a cylinder 222 which is subjected to the pressure of a control fluid through a conduit 224 at one end and is vented to atmosphere through an opening 226 at its other end.

Before describing in detail the mode of operation of the apparatus shown in Fig. 1, it is desired to point out that the column may normally be operated with a pressure on the order of 6 or 7 p. s. i., and in order to evaporate liquid oxygen with the latent heat of condensation of air under pressure in the condenser 78, the pressure of the air in the condenser should be on the order of 70 p. s. i. Accordingly, the valve 110 is adapted to open when the pressure in conduit 83 reaches 70 p. s. i., for a reference pressure of 7 p. s. i. The expansion engine, when working with the later cutoff, has an expansion through it at

least substantially equal to the difference between 158 p. s. i., the pressure in line 70, and the pressure in the line 77. Thus the expansion engine provides a pressure drop on the order of 83 p. s. i. This 83 p. s. i. drop, plus the 70 p. s. i. pressure previously mentioned, plus the differential in pressure of about 2 p. s. i. provided by the resistor 51, gives a cumulative pressure of 160 p. s. i.; and that is the pressure at which the two-stage compressor, not shown, delivers air as long as the reference pressure is 7 p. s. i. The reference pressure is substantially identical with column pressure, so that when the column pressure rises, the pressure which opposes expansion of the bellows rises, and an increase in the supply of upstream pressure is necessary to open the valve or keep it open.

Another valuable function of passing a portion of the entering air through the evaporator-condenser resides in the fact that under varying conditions, the expansion engine, though it may normally take a certain percentage of the air to be processed, may at times take somewhat larger quantities; by having a substantial stream of air normally passing through the evaporator-condenser, there is available, in the event the expansion engine requires more air by virtue of fortuitous changes in operating conditions, air in the system which can be diverted and supplied to the expansion engine and so enable the supply pressure to the latter to be maintained constant.

Operation

The mode of operation of the described apparatus during the production of oxygen is different, depending upon whether 50-pound oxygen or oxygen suitable for cylinder charging (say at 2000 p. s. i.) is being produced. Oxygen at either pressure may be delivered. The mode of operation for the production of oxygen at 50 p. s. i. pressure will be described first, and then the differences when oxygen at 2000 p. s. i. is to be the product will be explained. Following this, a procedure to set the plant in operation will be described.

Air is supplied continuously, as above noted, through the conduit 11 at 300° K. and 160 p. s. i., from any suitable compressor. Ordinarily a two-stage compressor with an after-cooler may be used as the source of air supply.

The entering air contains water vapor and carbon dioxide. These are precipitated out of the air stream by cold supplied by the leaving streams of oxygen product and nitrogen. The carbon dioxide is largely deposited in the heat exchanger 22 upon the walls of the courses 22B and 22C, and the water vapor, as liquid water and as ice, in the courses 21B and 21C of exchanger 21; and it may be of interest at the present moment to point out that the liquid oxygen drawn from the chamber 101 in the column 73 through conduit 100, the strainer 97, and conduit 96, is pumped by the liquid oxygen pump 95 through the conduit 81, through the course 24A of heat exchanger 24, through the conduit 80, the course 23A of heat exchanger 23, conduit 79, the oxygen course 62 of the evaporator-condenser 60, the conduit 65, course 22A of heat exchanger 22, conduit 33, and the course 21A of the heat exchanger 21, and finally is delivered at the desired terminal pressure through the product delivery pipe 25.

As has been previously pointed out, the nitrogen leaving the column by way of the connection

72 passes through the conduit 71, through course 24C of heat exchanger 24, through conduit 68, through course 23D of heat exchanger 23, through conduit 53, through one or the other of the courses 22B or 22C of heat exchanger 22, through one or the other of the conduits 31 or 32, through one or the other of the courses 21B or 21C of heat exchanger 21, through one or the other of the conduits 15 or 16, and through the escape 13, having passed through appropriate passage means in the valve mechanism 12.

Thus it will be evident that the streams of oxygen and nitrogen passing through the heat exchangers 22 and 21 will cause the carbon dioxide and water vapor to be condensed, or condensed and frozen, on the walls of the passages in these exchangers through which the entering air may at any given moment be flowing, and that liquid and carbon dioxide snow sublimed, and be carried out, by the leaving nitrogen stream, of the passages in which they have been deposited.

A portion of the air which is passed through the heat exchangers 21 and 22 is caused to pass again through the heat exchanger 22, through a course 22D thereof, as previously explained, flowing through the conduit 52, course 22D, and conduit 66 and rejoining the main mass of air which passes, during the production of low pressure oxygen, through conduit 67; and the reunited streams pass through the conduit 70 and the conduit 91 into the expansion engine to be expanded therein and to be cooled by the performance of work during the adiabatic expansion of the fluid in the expansion engine. The flow through conduit 52, course 22D of heat exchanger 22, and conduit 66 is caused by the valve 51, which provides approximately a 2 pound difference in pressure at its opposite sides.

At this point it may be noted that, regardless of the pressure of the delivered product, some of the air supplied to the apparatus for treatment therein always passes through the expansion engine 18, and some of the air always passes through evaporator-condenser 60, the quantity of air passing through evaporator-condenser 60 being determined by the cutoff of the expansion engine. When the expansion engine operates with early cutoff, more air necessarily passes through evaporator-condenser 60. During the production of oxygen at 50 p. s. i., about 12% of the total mass of entering air passes through the air course 63 of evaporator-condenser 60 in heat exchange relation with the leaving oxygen product. When oxygen at 2000 p. s. i. is the desired product, as much as 60% of all the air may pass through the air course 63 of evaporator-condenser 60.

The air which leaves the heat exchanger 22 on its way to pass through the conduit 67 is at a temperature of 115° K. and a pressure of 160 p. s. i. gauge. At the downstream side of the restrictor device 51 the pressure is 158 p. s. i. gauge. The recirculated air which flows through the conduit 66 is at a pressure on the order of 158 p. s. i. and a temperature of 180° K. just before it joins the fluid stream in conduit 67. When the streams have been mingled in the conduit 70, all the air is at a temperature of 135° K. and a pressure of 158 p. s. i. The portion of the air which flows through the conduit 70 and does work in the expansion engine leaves the latter at a temperature of 110° K. and a pressure of 70 p. s. i. when 50-pound oxygen is to be produced.

This expanded air passes through the conduit

85, through course 23C of heat exchanger 23, and emerges at a temperature of 105° K. and a pressure of 70 p. s. i. gauge, and passes through the check valve 87 to mix with liquid air which has passed through valve 76, and there is formed a stream partially of liquid air and partially of expanded air at a temperature of 100° K. and a pressure of 70 p. s. i. It may be observed that the air from the air course 63 of the evaporator-condenser 60 emerges from heat exchanger 23 and enters the conduit 75 at a temperature of 112° K. and a pressure of 158 p. s. i. After passing through the expansion valve 76 and undergoing a drop in pressure of about 88 p. s. i., the liquid air is at the same pressure as the expanded air coming through conduit 88.

The mixture of liquid air and expanded air at a temperature of 100° K. and a pressure of 70 p. s. i. enters the condenser coil 78 and is condensed by reason of the giving up of heat in the process of vaporizing oxygen in the bottom of the column. The liquid air emerging from the condenser 78 is at a temperature of 96° K. and a pressure of 70 p. s. i., and after this liquid air has passed through valve 110 and has its pressure reduced by approximately 60 p. s. i., the liquid air will be at a temperature of 83° K. and a pressure of 9 p. s. i.

Following the jacketing of the oxygen strainer 97 and the liquid oxygen pump 95, the still liquid air will enter the top of the column at a temperature of 83° K. and a pressure of 7 p. s. i., and it will be rectified therein so that substantially pure oxygen (99.5% pure, at least) can be drawn from an appropriate point in the evaporator-condenser arranged in the bottom of the column at a temperature of 95° K. and a pressure of 7 p. s. i. This liquid oxygen will flow through the strainer 97, conduit 96, the liquid oxygen pump 95, the conduit 81, and the central courses, in series, of heat exchanger 24, heat exchanger 23, evaporator-condenser 60, heat exchanger 22, and heat exchanger 21, and emerge, when 50-pound oxygen is being produced, in the form of gaseous oxygen at the mouth of the product pipe 25.

When oxygen for cylinder charging is to be produced, the valve structure 106 will be operated, as described in detail below, to connect the conduits 105 and 109, and the expanded air leaving the expansion engine will then pass through the conduit 105, the valve structure 106, and the conduit 109 into the column, and the pressure of the air in the conduit 105 will be reduced substantially to that within the column; accordingly, no more expanded air will be discharged through the check valve 87, because this valve will be held closed by the pressure, on the order of 70 p. s. i., which subsists in the conduit 77.

At the time the valve structure 106 is operated to permit the exhaust from the expansion engine to pass substantially directly into the column through the conduit 109, the point of cutoff of the expansion engine 18 will be changed to make it much earlier in the working stroke as aforesaid. Since the speed of the expansion engine remains unaltered, much less—roughly half as much—air can go through the expansion engine. Consequently, the air which cannot flow through the conduit 67 and be passed through the expansion engine will of necessity go through the air course 63 of evaporator-condenser 60, and, having passed through course 23B of heat exchanger 23, this now much larger mass of air, perhaps 60% of the total mass, will pass through valve 76 and enter the

15

condenser coil 78 of the evaporator-condenser at the bottom of the column 73 and be liquefied therein. This larger volume could not be liquefied in the evaporator-condenser 60 and the heat exchanger 23 because the oxygen product, now at a much higher pressure, cannot be vaporized at the condensation temperature for air at 153 p. s. i.

The reduced volume of liquid air from condenser coil 78 will pass through the heat exchanger 24 by way of course 24B and next pass through conduit 83 and valve 110 and then, after jacketing the strainer 97 and the liquid oxygen pump 95, will be passed into the top of the column for rectification. A much smaller percentage of the total oxygen content of the air entering the apparatus will be delivered during the production of 2000-pound oxygen than during the production of 50-pound oxygen.

In starting up the apparatus, the valve 108 will be open and for a considerable period, on the order of two hours, the expansion engine will be operated with the relatively late cutoff. This will mean that most of the air will pass through the expansion engine, a desirable thing at this time because there would be no oxygen to effect condensation of air in evaporator-condenser 60. About 12% of the entering air will flow through the evaporator-condenser 60, heat exchanger 23, valve 16, condensing unit 78, exchanger 24, conduit 83, and through valve 110 through the jacket for the oxygen strainer 97, the jacket 113 for the liquid oxygen pump 95, and then through the conduit 114 and connection 115 into the top of the column 73. During a considerable portion of the starting operation—the cooling down period—this air will simply flow out through the conduit 71, etc. and be discharged.

The relatively large amount, about 88%, of the air which passes through the expansion engine 18 will pass into the column through the conduit 109, and it too will discharge through the conduit 71 to the atmosphere. As the unit cools down, a little liquid will commence to form, and as soon as this stage is reached, the expansion engine will be shifted to early cutoff, thus increasing the refrigeration, and for another period, perhaps an hour, the exhaust from the expansion engine will still continue to be discharged through the connection 109 into the column. When the liquid finally builds up high enough so that oxygen can be drawn through the conduit 100, the apparatus will be all ready to go to 2000-pound oxygen production; or, by closing the valve 108 and making the point of cutoff in the expansion engine much later, 50-pound oxygen can be produced. It will be noted that during the later stages of the cooling down operations, the by-pass valve 108 will still be open and the expansion engine will be working with an early cutoff, and that when the liquid level in the column reaches the overflow point, the machine will be ready to fill cylinders; but if 50-pound oxygen is desired, the by-pass valve can be closed and the cams arranged in the expansion engine for late cutoff.

Certain points not previously mentioned, or perhaps deserving reemphasizing, may be noted now with respect to the embodiment of the invention, from its apparatus aspect, which has so far been described.

As a portion—a minimum of about 12%—of the entering air always passes during normal operation through the evaporator-condenser 60 in heat exchange relation with the fluid flowing through the oxygen product line, there will always, as soon

16

as soon as low enough temperatures are attained, be some liquid passing into the top of the column.

During the cooling down period, and also when oxygen at 2000 p. s. i. is the desired product, the expanded air may enter the column through the valve controlled connection 109 at a point perhaps three-quarters of the way up the column, instead of having to pass around through heat exchanger 23, the conduit 86 and the check valve 87. Indeed, no air can then pass through the circuit last mentioned, because the air in the conduit 77 will be at a pressure so much greater than the pressure in conduit 86, as to maintain the check valve closed.

During the production of 50-pound oxygen, the main flow of expanded air (about 88%) passes into the top of course 23C of heat exchanger 23 and passes down through this heat exchanger in heat exchange relation both with liquid oxygen produced in the system and with the leaving nitrogen stream. The expanded air, at 105° K. and 70 p. s. i. pressure—the same pressure as at release from the expansion engine—then passes through the one-way check valve 87 and enters the condenser unit 78 in the bottom of the column, where it is condensed, its latent heat of condensation serving to evaporate liquid oxygen at a lower pressure in the bottom of the column.

The liquefied air goes into the bottom of heat exchanger 24 and gives up some of its heat to the nitrogen and to the liquid oxygen which also flow through exchanger 24, and then passes through valve 110, where there is a reduction in pressure on the order of 60 p. s. i., this resulting in a further cooling of the liquid air and some vaporization. After passing around the liquid oxygen filter which it jackets, the liquid air is used, as will be recalled, to jacket the liquid oxygen pump also, and it then enters the top of the column at a temperature of 83° K. and at a pressure of 7 p. s. i. gauge.

The process of rectification in the column results in there being available liquid oxygen in the evaporator-condenser at the bottom of the column, specifically in the chamber 101 surrounding the condenser unit 78, at a temperature of about 95° K. and a pressure of 7 p. s. i., while nitrogen, with a single column rectifier, containing from 7 to 10% oxygen, and at a temperature of 83° K. and a pressure of 7 p. s. i., passes out through the top of the column. The liquid oxygen is filtered as it passes to the liquid oxygen pump and is forced by the latter at a pressure commensurate with the desired product pressure successively through heat exchanger 24, heat exchanger 23, evaporator-condenser 60, heat exchanger 22, and heat exchanger 21 to the point of product delivery, absorbing from the entering air stream the heat necessary to vaporize it, when 50-pound oxygen is being produced, while passing through evaporator-condenser 60, and the absorbed heat resulting in a change of state of the entering air from gaseous to liquid form.

When 2000-pound oxygen is being produced, the liquid oxygen cannot be evaporated in the evaporator-condenser 60 and so there is simply a temperature increase of a few degrees in the oxygen passing through evaporator-condenser 60, the evaporator-condenser 60 then operating simply as a heat exchanger. Nevertheless, when oxygen at 2000 p. s. i. pressure reaches the cylinders to which product line 25 may be connected, this oxygen is in a vapor state.

It has been pointed out that valves 76 and 110

17

are pressure control valves, being adapted to maintain a given upstream or supply pressure at a given reference pressure. As is readily seen in Fig. 2, the upstream or supply pressure operates on the inside of the bellows, opposing the spring 156 and tending to open the valve. The reference pressure applies to the outside of the bellows and opposes opening of the valve. It can thus be seen that a predetermined differential of the upstream or supply pressure over the reference pressure is required, in order to open the valve. Valve 76 is thus entirely indifferent to the pressure on its downstream side. Therefore, so long as the upstream pressure on valve 76 does not change, its downstream pressure and the pressure reduction across valve 76 are wholly determined by the operation of valve 110, and the operation of valve 110 depends on its spring setting and column pressure.

Inasmuch as the supply or upstream pressures desired in the conduits 75 and 83 are not identical, it may be pointed out here that the different valve-opening pressures may be provided for by using different sized springs for the two different valves where the spring 156 is indicated in Fig. 2. It is desirable that the upstream or supply pressure be regulated according to column pressure, because an increased column pressure will result in an increased boiling point for the oxygen in the lower end 101 of the column, necessitating a greater pressure in the coil 78, in order that air may be condensed at the now increased pressure of vaporizing oxygen. This increased pressure in coil 78 is provided by subjecting the outside of the bellows of valve 110 to the column pressure by means of the pressure conduit 172 which taps into the nitrogen line at a point close enough to the column to give a reference pressure substantially identical with column pressure.

With the upstream pressure on valve 110 increased, in order to increase the pressure in coil 78, it is also desirable to increase the upstream pressure on valve 76, in order to maintain approximately constant the pressure drop through valve 76. This effect is obtained by subjecting the outside of the bellows of valve 76 to column pressure by means of the pressure conduit 170.

During the production of 50-pound oxygen, the portion of the air that splits off the main stream in the header of evaporator-condenser 60—an amount which may be 12% of the whole during normal 50-pound oxygen production—is largely condensed in evaporator-condenser 60 and any excess that may pass through the evaporator-condenser 60 without liquefaction will be liquefied in the evaporator coil 78.

If 2000-pound oxygen is the product, no expanded air enters the evaporator-condenser 78 with the air going by way of exchanger 23 from the evaporator-condenser 60, as the low pressure of the expanded air—this air has been expanded through a much greater range of expansion when the expander is working with early cutoff—will not permit it to effect opening of the check valve 37. Note that the exhaust from the expansion engine communicates freely through the conduit 109 with the column at this time. The larger quantity of air going through the evaporator-condenser 60 and heat exchanger 23 and entering the condenser 78, even though little of it may have been condensed before the arrival at the condenser 78, is at a pressure of 70 p. s. i., which pressure is high enough to permit condensation of the air by the vaporization of oxygen at 7 p. s. i. in

18

chamber 101. The total quantity of oxygen produced when 2000-pound oxygen is being supplied will be proportionately much less than when 50-pound oxygen is the end product.

Roughly, during cylinder charging (2000-pound production) 40% of the air goes through the expansion engine and directly into the column, while the other 60% follows the course normally taken during 50-pound oxygen production by but 12% of the air supply to the apparatus. This change in the air flow distribution is due to the much earlier cutoff which occurs during 2000-pound oxygen production. It will be understood that the expansion engine operates at a predetermined speed, that the quantity of fluid which can pass through it is accordingly determined by the point of cutoff, and that, accordingly, with late cutoff, a much larger percentage of the total entering air stream can pass through the expansion engine than when cutoff is made early.

The detailed operation of the bypass valve of Figs. 4 through 7 may now be briefly reviewed. When fluid is admitted to cylinder 222 by way of conduit 224 in accordance with system requirements as explained in copending patent application Serial No. 122,078, filed October 18, 1949, and assigned to the assignee of this invention, piston 220 and rod 214 move downward as seen in Fig. 7, and protruding finger 206 moves the valve disc 188 off its seat, allowing fluid pressure from the chamber 107 to pass into the groove or chamber 212.

It will be noted that fluid at the pressure obtaining in conduit 105 is admitted to chamber 212 before valve 204 clears the cylindrical opening 202. Air starting to flow from chamber 107 through the central passage 183 will act on the relatively large valve member 204 and delay its downward movement sufficiently to prevent a blast of expanded air entering column 73 by way of chamber 208, passage 210 and conduit 109 with such force as to damage the column. In a very brief time the valve 204 will take the position shown in Fig. 5, in which position the valve 188 is completely open and permits free communication between conduit 105 and the column by way of circumferential ports 188, central passage 183, groove or chamber 212, cylindrical opening 202, chamber 208, passage 210, and conduit 109 into the column 73.

The foregoing description of the operation has been based on valves 76 and 110 arranged to be partially responsive to column pressure, as shown in Fig. 1. Consider now the embodiment shown in Figs. 1a and 1b, in which valves 76 and 110 are fixed-pressure-drop pressure reducing valves, one to effect a pressure reduction between its up- and downstream sides of 88 p. s. i. and the other of 60 p. s. i. The characteristic of these valves is that they provide a fixed difference in pressure between their up- and downstream sides. Unless it is possible to have such a differential in pressure, no fluid will flow past them. If the downstream pressure, say of the valve 110, is predetermined by the column pressure, then no pressure can flow through the valve 110 unless the pressure at its upstream side is at least equal to the column pressure plus the differential provided by the valve 110. And since the valve 110 will permit no flow past it until the 60 p. s. i. differential mentioned exists between the column pressure and the pressure at the upstream side of the valve 110, no fluid can be discharged past the valve 76 unless and until the pressure at its upstream side exceeds (by its pressure differential, 88 p. s. i.) the required pressure of 7 (column pressure) and

60 (pressure reducing valve 110's differential). The restrictor 51 adds 2 more p. s. i. to the accumulative pressure resulting from the addition of 7 p. s. i. plus 60 p. s. i. plus 88 p. s. i., and accordingly the compressor supplying air to the oxygen generator will discharge against a fixed minimum of pressure. More or less air can pass through the generator, but regardless of the quantity—there will be relatively little fluctuation with a compressor designed for use with the generator—the supply pressure will be maintained at on the order of 160 p. s. i., which allows about 3 p. s. i. for losses due to friction throughout the system.

The inventions disclosed herein are shown as applied to a single column rectifier. The application of these inventions to a double column rectifier may be understood by reference to the aforesaid patent application Serial No. 122,077 filed October 18, 1949.

The advantages of this invention lie in the provision of apparatus to produce oxygen or other gases which is self-regulating and well adapted to meet varying demands. The system provides for automatic operation with a great degree of flexibility, and assures that variations in column pressure will effect desired changes in the pressure of compressed air supplied to the system.

While there are in this application specifically described two forms which the invention may, from its system aspect, assume in practice, it will be understood that these forms of the same are shown for purposes of illustration, and that the invention, from the system aspect, may be modified and embodied in various other forms without departing from its spirit or the scope of the appended claims.

I claim:

1. In apparatus for producing substantially pure oxygen from compressed air, a rectifier column, a waste gas conduit, a connection for the waste gas conduit to the column, the connection being at column pressure, an expansion engine, a conduit connected to supply compressed air to the expansion engine, a pressure responsive expansion valve, a conduit connected to supply compressed air to the valve, an evaporator-condenser in the column, a conduit connected to conduct expanded air from the engine to the evaporator-condenser, a conduit connected to conduct expanded air from the valve to the evaporator-condenser, a second pressure responsive expansion valve, a conduit connected to conduct air from the evaporator-condenser to said second valve, a conduit connected to conduct air from the second valve to the column, and a pressure connection from each of the expansion valves to the waste gas conduit whereby the valves are responsive to the pressure in the waste gas conduit.

2. The apparatus of claim 1, in which the connections to the waste gas conduit are adjacent its connection to the column.

3. In apparatus for producing substantially pure oxygen from compressed air, a rectifier column, an expansion engine, an expansion valve having a pressure responsive member connected to actuate a closure member and arranged to be biased toward its open position by upstream pressure, means to conduct compressed air to the engine and expansion valve simultaneously, an evaporator-condenser in the column, means to conduct expanded air from the engine to the evaporator-condenser, means to conduct expanded air from the valve to the evaporator-condenser, a second expansion valve having a pressure re-

sponsive member connected to actuate a closure member and arranged to be biased toward its open position by upstream pressure, means to conduct air from the evaporator-condenser to the second valve, means to conduct expanded air from the second valve to the column for rectification, and a pressure conduit from a predetermined point in the apparatus to that side of the pressure responsive member of each valve opposite the side exposed to upstream pressure, whereby the pressure at that point opposes opening of the valve.

4. In the apparatus of claim 3, means alternatively to conduct expanded air from the expansion engine to the column by by-passing the evaporator-condenser.

5. The apparatus of claim 4, in which the predetermined point of claim 3 is substantially at column pressure.

6. The apparatus of claim 3, in which the predetermined point is substantially at column pressure.

7. In oxygen production apparatus having a compressed air source, a rectifier column, an evaporator-condenser in the column, an expansion engine connected to receive air from the compressed air source and having an exhaust connection into the evaporator-condenser: a bypass valve comprising a casing having an outlet connection to the column and including a passage forming a part of said engine exhaust connection to the evaporator-condenser, passage means arranged to connect the engine exhaust with the column, a valve in the passage means adapted to close the passage against fluid flow, means to open the valve, and pressure responsive means associated with the valve opening means and exposed upon valve opening to engine exhaust pressure and connected to delay complete opening of the valve.

8. In oxygen production apparatus having a compressed air supply source and a column, a pair of expansion valves arranged in series between the air supply source and the column, each valve having a pressure responsive closure operator which is arranged to be biased toward valve-opening position by upstream pressure, and a pressure conduit substantially at column pressure connected to each valve to oppose the upstream pressure.

9. In oxygen production apparatus having a compressed air supply source and a column, a pair of expansion valves arranged in series between the air supply source and the column, each valve having a bellows operated closure member in which one side of the bellows is subjected to upstream pressure and is arranged to have upstream pressure bias the bellows toward valve opening position, and a conduit substantially at column pressure connected to the valve to subject the opposite side of the bellows to column pressure.

10. In oxygen production apparatus having a compressed air source, a rectifier column, an evaporator-condenser in the column, an expansion engine connected to receive air from the compressed air source and having an exhaust connection into the evaporator-condenser: a bypass valve comprising a casing having an outlet connection to the column and including a passage forming a part of said engine exhaust connection to the evaporator-condenser and passage means arranged to connect the engine exhaust with the column, the passage means including a

21

valve seat member having a passage therethrough and a cylindrical opening, a valve cooperable with the valve seat member and movable to open and close the passage against fluid flow, means to open the valve, and a member associated with the valve opening means and being reciprocable in the cylindrical opening, the last-named member being exposed to engine exhaust pressure upon opening of the valve and being connected with the valve to delay complete opening thereof upon initial exposure to the engine exhaust pressure.

WIN W. PAGET.

22**REFERENCES CITED**

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,395,466	Barbet -----	Nov. 1, 1921
1,626,345	LeRouge -----	Apr. 26, 1927
2,213,338	DeBaufre -----	Sept. 3, 1940
2,360,468	Brown -----	Oct. 17, 1940