Jan. 26, 1954 S. C. COLLINS 2,667,044

APPARATUS FOR AND METHOD OF SEPARATING GASES

Filed Feb. 9, 1951 2 Sheets-Sheet 1

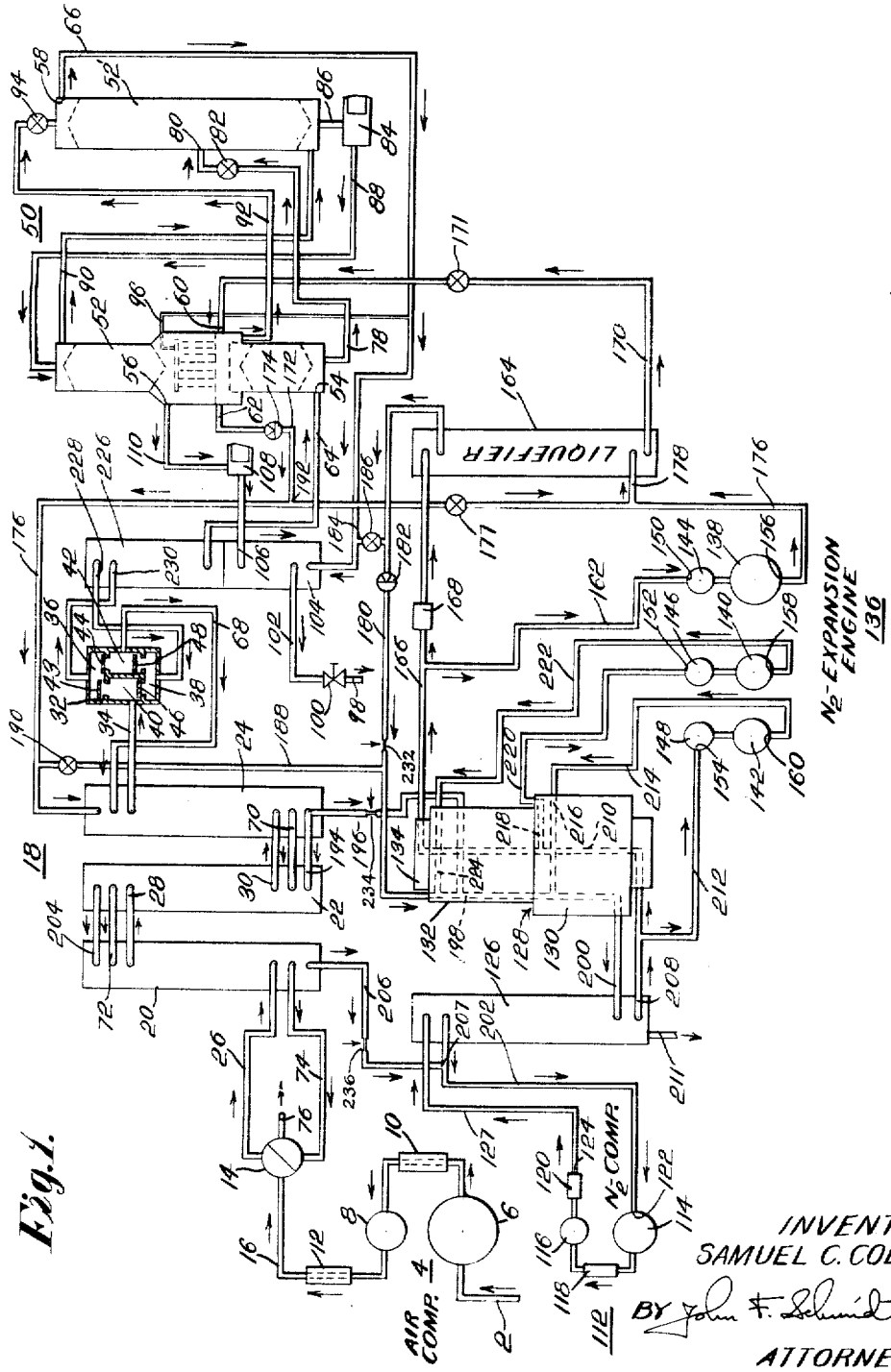

Fig. 1.

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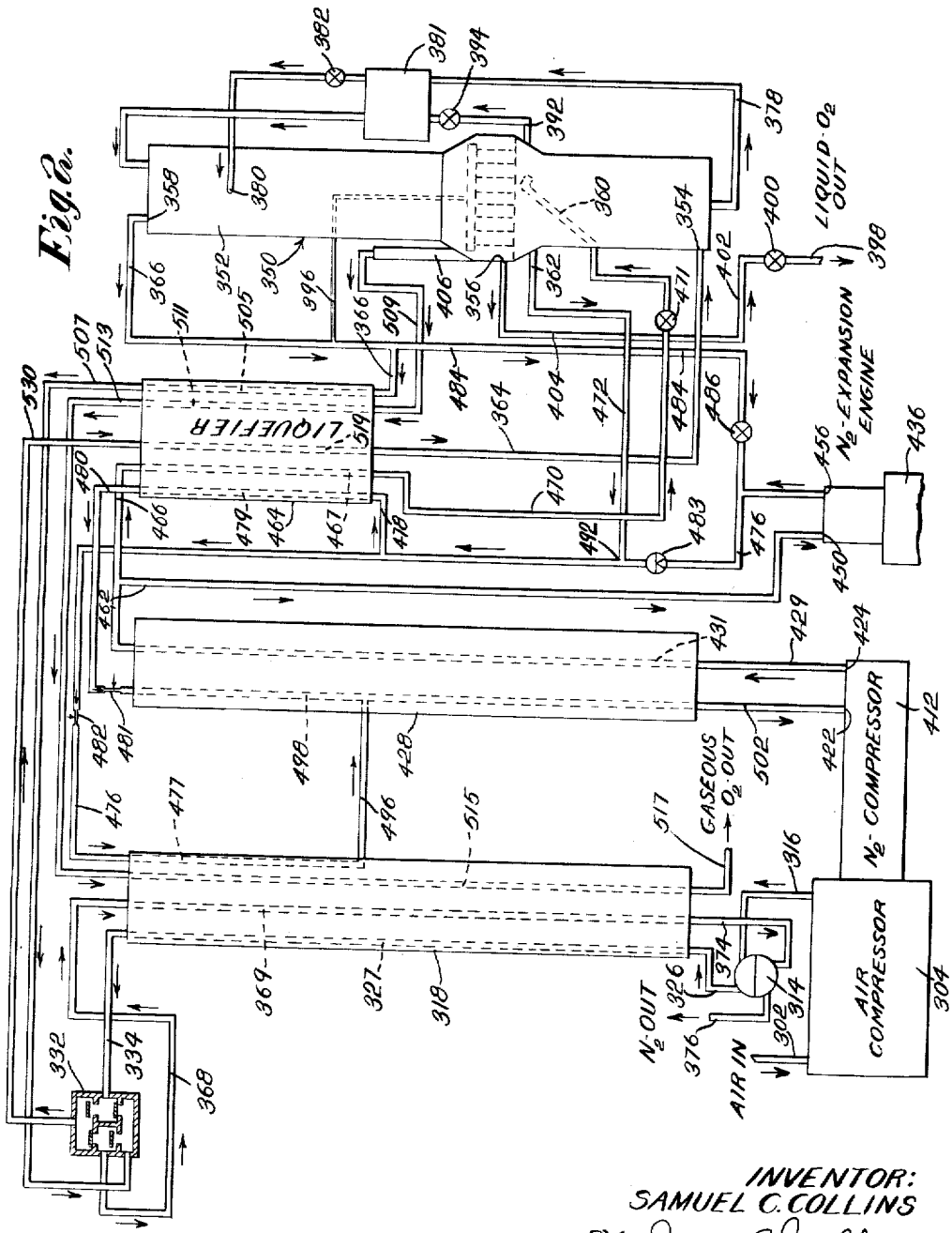
Fig. 2.



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APPARATUS FOR AND METHOD OF SEPARATING GASES

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This invention relates to the separation of gases into their constituents, especially to the separation of air into oxygen and nitrogen.

The separation of air into its components is quite readily accomplished at low temperatures by taking advantage of the different boiling points of oxygen and nitrogen. This method of separation of course requires refrigeration, and it is common practice to utilize the low temperature of the products—the separated oxygen and nitrogen—to cool the incoming air. This method is based on a nice balance between cooling required by inflowing air and refrigeration available in the cold products, with losses made up by added refrigeration provided by expanding some of the air in doing external work. Under certain circumstances, it is desirable to produce oxygen in the liquid form. When oxygen is taken out as liquid, there is necessarily a substantial refrigeration loss which must be made up in some manner.

It is an object of this invention to provide an apparatus and method for the production of oxygen, preferably in the liquid form. This and other objects are accomplished in an apparatus and method in which a primary circuit comprises the main air circuit, the product oxygen, and the effluent waste gases, and a secondary circuit comprises a refrigeration circuit, preferably nitrogen gas being circulated as a refrigerant.

In the drawings:

Fig. 1 is a diagram showing apparatus for accomplishing the purpose set forth above, in which the secondary circuit shows a three-stage expansion engine; and

Fig. 2 is another embodiment of the invention in which the secondary circuit employs a single-stage expansion engine, and in which the oxygen product may be taken out as liquid or in the alternative as gas.

In the embodiment shown in Fig. 1, an air inlet 2 is shown as a conduit connected to the intake of an air compressor 4. The compressor 4 is preferably a two-stage compressor having a low pressure stage 6, a high pressure stage 8, an intercooler 10, an aftercooler 12, and appropriate connecting conduits, as will be understood by those skilled in the art. The compressor 4 thus comprises a source of air under pressure.

A reversing valve is shown at 14 connected with the source of air under pressure by first-named conduit means 16. A reversing heat exchanger is provided as indicated generally at 18. The invention preferably comprises at least one reversing heat exchanger, but it may be desirable

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to divide the heat exchanger 18 into three small heat exchangers 20, 22 and 24 in order to keep the height of the unit to a minimum. Reversing heat exchanger 18 is connected with the reversing valve 14 by second-named conduit means 26. Where the heat exchanger 18 is broken down into three separate units, similar fluid passages in units 20, 22 and 24 are connected together by means of conduits 28 and 30, the conduits 28 and 30 forming with said passages and with the conduit 26 one continuous fluid passage.

A second reversing valve 32 is shown connected with the heat exchanger 18 by third-named conduit means 34. The reversing valve 32 may if desired be similar to the reversing valve 14 and be mechanically operated, or the valve 32 may in the alternative be a reversing check valve, as shown diagrammatically in Fig. 1. A reversing check valve such as is shown in Fig. 1 may be provided with chambers 36, 38, 40, and 42, chambers 38—40, 38—42, 40—36, and 42—36 being provided with suitable interconnecting openings. Check valves 43, 44, 46, and 48 are provided to engage suitable seats surrounding the aforesaid openings, as will be well understood by those skilled in the art.

A rectification column 50 is shown, the column being preferably of the double-column type provided with suitable packing which may be any rather porous substance such as stainless steel or brass fine mesh screen in the shape of saddles or any other suitable shape. As in the case of the heat exchanger 18, the column 50 may be made of a smaller height by making the upper portion of the upper column in two parts. Thus, as here shown, the upper column is provided in two sections 52 and 52'.

The rectification column has an air inlet 54, an oxygen product outlet 53, a nitrogen effluent outlet 58, secondary circuit inlet and outlet connections 60 and 62 respectively, and other connections which will be described below. Means are provided to connect the second reversing valve 32 with the air inlet 54. These means include fourth-named conduit means 64, which might be connected directly with the second reversing valve 32, but in the preferred form will include other elements as will be described below.

Means are also provided to connect one of the product outlets with the second reversing valve; in the embodiment shown in Fig. 1 this means includes fifth-named conduit means 66 connecting directly with the nitrogen effluent outlet 58; conduit 66 might connect directly with the reversing valve 32, but in the preferred form of the

invention connects with valve 32 by way of additional means as will be described in greater detail below. Sixth-named conduit means 68 are provided to connect the second reversing valve 32 with another passage in heat exchanger 18.

As was indicated above, in the embodiment shown the heat exchanger 18 is broken down into three separate units 20, 22 and 24; the sixth-named conduit means 68 referred to above connects with one end of one of the passages in unit 24, and a conduit 70 connects the other end of that passage of unit 24 with a similar passage in unit 22; the other end of that passage in unit 22 communicates by way of a conduit 72 with one end of a similar passage in unit 20, and the other end of that passage connects by way of seventh-named conduit means 74 with the first-named reversing valve 14. Reversing valve 14 is provided with a waste gas effluent (or nitrogen product) outlet 76.

Returning now to the rectification column, indicated generally by the reference character 50, the oxygen-rich liquid air outlet at the bottom of the lower column is connected by a conduit 78 with a liquid inlet 80 in the upper column section 52'. As will be well understood by those skilled in the art, the inlet 80 is provided at that point in the column section where the equilibrium operating condition provides down-flowing liquid of substantially the same composition as the ingoing oxygen-rich liquid air. The conduit 78 is provided with an expansion valve 82.

Liquid collecting in the bottom of the upper column section 52' is pumped to the top of the upper column portion 52 by way of any suitable liquid pump 84 and connecting conduits 86 and 88. It will of course be understood by those skilled in the art that, where there are no height limitations imposed upon the apparatus (see the description of Fig. 2 below), the upper column section 52' may if desired be stacked immediately on top of the upper column section 52, in which case liquid trickling downward through the column will simply fall the entire length of the upper column and there will then be no need for the connecting conduits 86 and 88 and the liquid pump 84.

The upper column section 52 discharges its vapor reflux by way of a conduit 90 to the lower end of the upper column section 52'. Again, it will be understood by those skilled in the art, that an apparatus which has no height limitations will not require the conduit 90 if the upper column section 52' is stacked immediately on top of the column section 52, so that the vapor reflux or gaseous effluent may flow directly from the upper end of the column section 52 into the column section 52'. As a matter of fact, there will be no dividing boundary or partition between the sections 52 and 52', but there will be instead one continuous upper column section (as in Fig. 2, described below).

Nitrogen-rich liquid collecting in the nitrogen shelf of the lower column section may be transferred therefrom to the upper end of the upper column section 52' by a suitable conduit 92. A restriction such as the expansion valve 94 is provided in the conduit as will be understood by those skilled in the art.

A rare gas bleed 96 connects the upper portion of the boiler-condenser in the middle of the double-column with the waste gas or nitrogen effluent line 66. It will be understood by those skilled in the art that a bleed such as the conduit 96 shown is provided to prevent the accumulation of uncondensable—i. e., at the normal operating temperatures encountered—gases in the upper portion of the boiler-condenser in the middle of the column. Without such a bleed uncondensable gases are likely to accumulate and render the column inoperative. Bleed line 96 may be of such small conduit as to limit fluid flow therethrough to the very small percentage required, to avoid wasting gas, or if desired, a variable restriction, not shown, may be provided in the bleed line.

Liquid oxygen product is taken from the boiler-condenser in the middle of the column by way of an outlet 98 connecting through a valve 100 with an outlet conduit 102. Outlet conduit 102 connects with a subcooler 104 having a liquid oxygen passage therethrough, the other end of which connects with a conduit 106 which receives liquid oxygen from any suitable liquid pump 108; the pump in turn is connected with the product outlet 56 by a conduit 110. The subcooler has another passage through it and connects with the waste gas effluent line 66 and is an additional means (additional to the fifth-named conduit means 66 referred to above) connecting the nitrogen product outlet 58 with the second reversing valve 32.

The subcooler 104 serves to cool the liquid oxygen product below its boiling point at storage pressure sufficiently to prevent excessive loss of liquid upon the emptying of such oxygen from the column through the valve 100 to such storage facilities as may be provided.

Reference will now be made to the secondary or refrigeration circuit of this apparatus. In this circuit there is a nitrogen compressor indicated generally at 112, which is preferably a two-stage compressor having a low pressure stage 114, a high pressure stage 116, an intercooler 118, and an aftercooler 120. Compressor 112 has the usual inlet and discharge connections 122 and 124, respectively.

There is a second-named heat exchanger which, again, may if desired be in a single unit, but which in the embodiment show in Fig. 1 consists of a plurality of units. One such unit is that shown at 126, which has a passage connecting with the discharge connection 124 by first-named secondary circuit conduit means 127. Another unit of the second-named heat exchanger is shown generally at 128 and consists of sections 130, 132 and 134. Units 126 and 128 are interconnected by suitable conduits as will be explained in detail below.

An expansion engine 136 is provided in the secondary circuit. This expansion engine may if desired be a single cylinder engine, but in the preferred form, comprises a three-stage expansion engine having cylinders 138, 140 and 142. As used here, "three-stage" means that the expansion takes place at three different temperature levels. The expansion engine stages are preferably provided with any suitable surge capacity indicated at 144, 146 and 148. Each stage of the expansion engine is of course provided with intake and exhaust ports. For the purpose of this description, it will be assumed that the intakes to the surge capacities constitute the intakes for the expansion engine cylinders. Thus, the stages 138, 140 and 142 have intake ports 150, 152 and 154 respectively, and exhaust ports 156, 158 and 160.

A single-stage expansion engine would have its intake port connected with the second-named heat exchanger by a single simple conduit. In the embodiment shown in Fig. 1, the stage 138 having the intake port 150 is connected with the second-named heat exchanger by means which include second-named secondary circuit

conduit means 162. A liquefier 164 is provided and is connected with the second-named heat exchanger by third-named secondary circuit conduit means 166. If desired, a trap or filter 168 may be provided in the third-named secondary circuit conduit means 166.

A liquid conduit 170 is connected with the liquefier 164 and with the aforesaid secondary circuit column inlet connection 60. An expansion valve 171 is provided in the line 170. Means are provided to connect the expansion engine exhaust port 156 with the compressor inlet connection 122, those means including the liquefier and the second-named heat exchanger. Means, including fourth-named secondary circuit conduit means 172, are provided to connect the secondary circuit column outlet connection 62 with the last-named means. A check valve 174 in the conduit means 172 permits fluid flow only in the direction away from the column.

The means provided to connect the expansion engine exhaust port 156 with the compressor inlet connection 122 will now be described in greater detail. As aforesaid, those means include the liquefier 164 and the heat exchanger 126, 128. More specifically, a conduit 176 having a shut-off valve 177 connects at its one end with the expansion engine exhaust gas outlet 156 and at its other end connects with one end of a passage in unit 24 of reversing heat exchanger 18. Conduit 176 is provided with a branch 178 connecting with one end of a passage in liquefier 164; the other end of that passage connects by way of a conduit 180 with section 132 of unit 128 of the second-named heat exchanger. A check valve 182 in the conduit 180 limits flow in conduit 180 from the liquefier toward the second-named heat exchanger 126, 128. A conduit 184 having a normally-closed shut-off valve 186 connects the nitrogen effluent line 66 with the conduit 180. Another conduit 188 having a normally-closed shut-off valve 190 connects the conduit 176 with the conduit 180. The fourth-named secondary circuit conduit means 172 referred to above as part of the means connecting the secondary circuit column outlet connection 62 with the means to connect the expansion engine exhaust port and the compressor inlet connection accomplishes that function by connecting with conduit 176 at 192. Conduit 172 and a part of conduit 176 thus comprise means to connect the column outlet connection 62 with the heat exchanger 18.

Conduit 176 was referred to above as connecting at one end with unit 24 of heat exchanger 18, that connection being with a passage in unit 24. The other end of that passage in unit 24 connects with two conduits, 194 which goes to unit 22, and a conduit 196 which connects the aforesaid passage in unit 24 with a passage 198 in unit 128. Conduit 180 is connected as aforesaid with one end of passage 198; passage 198 is continuous through the unit 128 and connects at its other end with a conduit 200. Conduit 200 connects with one end of a passage in unit 126, the other end of which passage in unit 126 connects with a conduit 202, which in turn is connected with the compressor inlet 122.

Conduit 194, referred to above as connecting units 24 and 22 of heat exchanger 18, connects with one end of a fluid passage in unit 22, the other end of which connects with a conduit 204 which in turn connects with a fluid passage in unit 20. The other end of that fluid passage connects with a conduit 206, which connects at 207 with the conduit 202 referred to above.

As will be pointed out in the discussion of the embodiment of the invention shown in Fig. 2, the expansion engine for the secondary circuit may if desired be a single cylinder engine. However, in the embodiment shown in Fig. 1, expansion of the refrigerant is preferably accomplished in three stages, this taking place in a three-cylinder expansion engine, or in any other suitable manner as will be understood by those skilled in the art.

As was pointed out above, the second-named heat exchanger 126, 128 is connected with the expansion engine intake. More specifically, the nitrogen compressor discharge 124 is connected as aforesaid by a conduit 127 with one end of a passage in heat exchanger 126, 128, this passage being in the unit 126. The other end of the passage referred to is connected by a conduit 208 with a fluid passage in the unit 128, more specifically with a passage 210 in section 134, this passage being common to sections 134, 132 and 130. The other end of passage 210 is connected with the conduit 166 referred to above. A purge line 211 is provided in unit 126 for the draining of impurities.

A branch conduit 212 connects with the conduit 208 and with the inlet port 154 of the first stage of expansion engine 136. The exhaust port 160 of the first stage of the expansion engine connects by way of a conduit 214 with a passage 216 in section 130 of unit 126. Passage 216 is connected with the passage 198 of that unit.

A branch passage 218 connects with passage 210 and connects at its outlet with a conduit 220. Conduit 220 is connected at its other end to the intake of the second stage of the expansion engine, namely the intake port 152 provided in the surge capacity 146. The exhaust port 158 of second stage 140 is connected by a conduit 222 with a passage 224 in section 132. Passage 224 is in communication with the passage 198.

Reference was made above to the means to connect product outlet 58 with the second reversing valve 32, those means including the fifth-named conduit means 66. It was further pointed out that those means include a passage in the subcooler 104. It will now be noted that a heat exchanger 226 is mounted atop the subcooler 104. The nitrogen line 66 connects with a passage in subcooler 104 which connects directly with a passage in heat exchanger 226. The other end of that passage connects with a conduit 228, and conduit 228 connects with chamber 38 of valve 32. Heat exchanger 226 is provided with another passage which is connected at its one end with a conduit 230, and at its other end with the fourth-named conduit means 64 referred to above. Conduit 230 connects the passage referred to with the chamber 36 of reversing valve 32.

In order to permit the desired balancing of flows, variable restrictions 232, 234, and 236 are provided in conduits 180, 196, and 206 respectively.

Reference is now made to the embodiment of the invention shown in Fig. 2, wherein an air intake 302 connects with the intake of an air compressor 304. The discharge of the compressor 304 connects with a reversing valve 314 by means of first-named conduit means 316. Reversing valve 314 connects with a reversing heat exchanger 318 by second-named conduit means 326. Conduit 326 connects with a fluid passage 327 in heat exchanger 318. The passage 327

connects with a second reversing valve 332 by third-named conduit means 334.

The reversing valve 332 shown in Fig. 2 is substantially identical with the reversing valve 32 shown in Fig. 1, both of these valves being shown as reversing check valves; however, if desired, reversing valve 332 may be identical with reversing valve 314, and mechanically connected to operate at the same time that valve 314 is operated.

A rectification column 350 is provided, this column preferably being of the double-column type somewhat similar to the column shown at 50 in the embodiment of Fig. 1, except that the upper column 352 (Fig. 2) is shown in a single section integral with the lower column, because it is assumed that the embodiment shown in Fig. 2 does not have the height limitations which are imposed on the embodiment shown in Fig. 1.

Rectification column 350 has an air inlet 354, an oxygen product outlet 356, a nitrogen effluent outlet 358, secondary circuit inlet and outlet connections 360 and 362 respectively, and other connections which will be described below. Means are provided to connect the second reversing valve 332 with the air inlet 354. These means include fourth-named conduit means 364, which may if desired be connected directly with the second reversing valve 332, but in the preferred form will include other elements as will be described below.

Means are also provided to connect one of the product outlets with the second reversing valve; in the embodiment shown in Fig. 2, this means includes fifth-named conduit means 366 connecting directly with the nitrogen effluent outlet 358; conduit 366 may if desired connect directly with the reversing valve 332, but in the preferred form of the invention, connects with valve 332 by way of additional means as will be described in greater detail below. Sixth-named conduit means 368 are provided to connect the second reversing valve 332 with another passage 369 in heat exchanger 318. The other end of passage 369 is connected with seventh-named conduit means 374, which connects with the reversing valve 314. Reversing valve 314 is provided with a waste gas effluent (or nitrogen product) outlet 376.

Returning now to the rectification column indicated generally by the reference character 350, the oxygen-rich liquid air outlet at the bottom of the lower column is connected by a conduit 378 with a liquid inlet 380 in the upper column 352. The conduit 378 may if desired pass through a heat exchanger 381, and includes a restriction such as the expansion valve 332. Nitrogen-rich liquid collecting in the nitrogen shelf of the lower column may be transferred therefrom to the upper column by a suitable conduit 392, this conduit preferably passing through the heat exchanger 381. A restriction such as the expansion valve 394 is provided in the conduit for reasons that will be understood by those skilled in the art.

As in the embodiment shown in Fig. 1, a rare gas bleed 396 is preferably provided from the upper portion of the boiler-condenser in the middle of the double column, the bleed connecting with the waste gas or nitrogen effluent line 366.

The product oxygen outlet 356 is preferably provided in the form of a tap into the liquid collecting pot or boiler-condenser in the middle of the column. Where the oxygen product is desired in the liquid state, it may be removed through a tap or outlet 398 connecting through a valve 400 with an outlet conduit 402. Outlet conduit 402 connects with the liquid oxygen outlet 356 by a connecting conduit 404. When it is desired to remove oxygen from the column in the vapor state, that is accomplished through an outlet 406, that outlet being in the form of a substantially vertical stack portion which allows droplets to fall out of the vapor stream back into the column.

Reference will now be made to the secondary or refrigeration circuit of the apparatus shown in Fig. 2. In this circuit there is a nitrogen compressor 412 which may if desired be driven from the same source of power as the air compressor 304. Compressor 412 has the usual inlet and discharge connections 422 and 424 respectively.

There is a second-named heat exchanger 428 which, in the embodiment shown in Fig. 1, was shown as consisting of a plurality of units, but which in the embodiment shown in Fig. 2 now being described preferably consists of a single unit as shown. First-named secondary circuit conduit means 429 connects the discharge 424 of compressor 412 with a passage 431 in heat exchanger 428.

An expansion engine 436 is provided in the secondary circuit. This expansion engine is desirably a single cylinder engine having intake and discharge ports 450 and 456 respectively. Intake port 450 is connected with passage 431 of the second-named heat exchanger 428 by second-named secondary circuit conduit means 452. A liquefier 464 is provided; a passage 467 thereof is also connected with passage 431 of the second-named heat exchanger 428 by third-named secondary circuit conduit means 466, and a portion of the conduit means 462. A liquid conduit 470 is connected with the other end of passage 467 in liquefier 464 and with the aforesaid secondary circuit column inlet connection 360. A combined shutoff and expansion valve 471 is preferably provided in the line 470.

Means are provided to connect the expansion engine exhaust port 456 with the compressor inlet connection 422, those means including the liquefier 464 and heat exchangers 318 and 428. Fourth-named secondary circuit conduit means 472 are provided to connect the secondary circuit column outlet connection 362 with the last-named means.

Referring to the "last-named means" in greater detail, a conduit 476 connects with the expansion engine exhaust gas outlet 456 at its one end and at its other end connects with a passage 477 in the cold end of reversing heat exchanger 318. Conduit 476 is provided with a branch 478 connecting with one end of a passage 479 in liquefier 464; the other end of passage 479 connects by way of a conduit 480 with the second-named heat exchanger 428. Variable restrictions 481 and 482 in the conduits 480 and 476 respectively are preferably provided to enable balancing of the fluid flows in the two lines at the desired ratio.

A check valve 483 is preferably provided in the conduit 476 to permit fluid flow only in the direction from the expansion engine toward heat exchanger 428. A conduit 484 having a normally closed shutoff valve 486 connects the nitrogen effluent line 366 with the conduit 476. The fourth-named secondary circuit conduit means 472 referred to above connects with conduit 476

at 492. Conduit 476 was referred to above as connecting at one end with a passage 477 in heat exchanger 318. The other end of passage 477 connects by way of a conduit 496 with a passage 498 in heat exchanger 428. Passage 498 extends substantially throughout the length of heat exchanger 423 and is connected at its one end with the conduit 480, and at its other end with a conduit 502 which connects with the inlet 422 of the nitrogen compressor.

Reference is made above to the means to connect product outlet 358 with the second reversing valve 332, those means including the fifth-named conduit means 356. Those means also include a passage 505 in liquefier 464, one end of which is connected with the effluent line 396 and the other end of which is connected with a conduit 507. Conduit 507 is connected with the reversing check valve 332.

The foregoing description referred to the desirability at times to remove oxygen product in the vapor state. When gaseous oxygen is desired, it is possible to utilize the refrigeration present in the cold oxygen product. This may be accomplished in the manner shown in Fig. 2, whereby a conduit 509 is connected to the upper end of the stack portion 406, and connects with a passage 511 in liquefier 464. A conduit 513 connects the other end of passage 511 with a passage 515 in heat exchanger 318. An outlet connection 517 connects with the passage 515 and may conduct the gaseous oxygen to any desired oxygen utilizer, for example a booster pump which raises the pressure of the gaseous oxygen to a high value for the purpose of storing the oxygen in bottles, or to some lesser pressure direct to a shop line.

The above description indicates that fourth-named conduit means 364 forms one of the elements of the means to connect reversing valve 332 with air inlet 354. Another element is passage 519 in liquefier 464, one end of which connects with conduit 364 and the other end of which connects with still another element, conduit 530, which in turn connects with valve 232.

Operation

Reference is now made to the operation of the embodiment of the invention shown in Fig. 1. In the discussion of the operation of this embodiment, the practice of the method of this invention will simultaneously be described. Normal operation under equilibrium conditions will be described first, after which the operation to cool down or start the apparatus will be described.

Compressed air at approximately 88 p. s. i. g. and 110° F. is supplied by the air compressor 4, passing through conduit 16, reversing valve 14, and conduit 26, to the reversing heat exchanger 18. The air passes through a passage in unit 20, from thence to unit 22 by way of conduit 28, through a passage in unit 22, from there to a passage in unit 24 by way of conduit 30, and leaves the reversing heat exchanger 18 by way of conduit 34.

Conduit 34 conducts air to the reversing check valve 32, namely to chamber 40 of valve 32. The compressed air lifts valve 43 off its seat, and thus flows into chamber 36 and out through conduit 230 to the heat exchanger 226. Air enters heat exchanger 226 at −262° F. and at 87 p. s. i. g. Air leaves the heat exchanger 226 by way of the conduit 64 and enters the lower column by way of the air inlet 54, at −275° F. and at 87 p. s. i. g., and approximately 6% of the air by weight is liquid.

The effluent gases, mostly nitrogen, leaving the column by way of conduit 66 are at approximately 7 p. s. i. g. and at −314° F. The effluent gases pass through subcooler 104 and heat exchangers 226 and 18 in turn, giving up their refrigeration and absorbing heat from the incoming air. The effluent gases leave heat exchanger 226 and enter heat exchanger 18 at −269° F. and 6 p. s. i. g., and leave the connection 76 at approximately 104° F. and atmospheric pressure.

Liquid oxygen product leaves the column by way of conduit 110 at a temperature of −290° F. and a pressure of 7 p. s. i. g., and passes through the subcooler 104 to storage under pressure, coming out of the subcooler at approximately −298° F. and 20 p. s. i. g. With liquid oxygen product outlet 56 located at the normal liquid level, product oxygen leaves the column, in the liquid form, as liquid tends to build up above the normal level. Thus, product oxygen overflows through the conduit 110 and is pumped to storage through the aforesaid path.

Referring now to the secondary circuit, compressed nitrogen leaves the nitrogen compressor 112 by way of conduit 127 at approximately 450 p. s. i. g. and approximately 110° F. This nitrogen passes to the unit 126 of the second heat exchanger, and leaves unit 126 by way of conduit 208 at approximately 450 p. s. i. g. and 44° F. A portion (approximately 14.8%) of the nitrogen is taken from conduit 208 by way of conduit 212 to the first-stage cylinder 142 of the expansion engine 136. This portion is expanded isentropically to a pressure of approximately 84 p. s. i. g. and a temperature of −770 F., leaving the first stage by way of conduit 214 and going to passage 216 in section 130 of the unit 128 of the second-named heat exchanger. In section 130, passage 216 joins passage 198, and the gases pass by way of conduit 200 at 32° F. and 82 p. s. i. g. to the unit 126, leaving the unit 126 at 81 p. s. i. g. and 103° F.

Reference was made to a portion (14.8%) of the nitrogen being taken from conduit 208 by way of branch conduit 212. The remainder (85.2%) of the gas in conduit 208 passes to the section 134, namely passage 210 in section 134, and this portion is again divided. Some (29.8%) of the remaining nitrogen is taken from the passage 210 by way of passage 218 and conduit 220 at −73° F. and 450 p. s. i. g. This portion is expanded isentropically to 85 p. s. i. g. in the second stage 140 of the expansion engine 136, and leaves the second stage at −168° F. by way of conduit 222, passing to unit 128. More specifically, conduit 222 connects with passage 224 in section 132, and passage 224 connects with passage 198.

Reference is made to the above discussion of the passage 210 and the branch 218 which takes some 29.8% of the nitrogen from passage 210. The remainder (about 70.2%) of the nitrogen from passage 210 leaves the unit 128 by way of conduit 166 at −199° F. and 450 p. s. i. g. A portion thereof (85%) is tapped off by way of conduit 162 for the third stage of isentropic expansion in cylinder 138 of expansion engine 136. Here the nitrogen expands from approximately 450 p. s. i. g. and −199° F. to 87 p. s. i. g. and −280° F.

The exhaust from cylinder 138 passes to liquefier 164 by way of conduits 176 and 178, being joined in 178 by a portion of the gas from connection 62. The exhaust from stage 138 is

at −280° F. and 87 p. s. i. g. Gas from connection 62 and flowing downward in conduit 176 is at −282° F. and 87 p. s. i. g. They mix in conduit 178 and enter the liquefier at close to −280° F. (over 96.9% of the gas in conduit 178 comes from cylinder 138) and at 87 p. s. i. g. The resultant mixture enters liquefier 164 from conduit 178 and gives up its refrigeration to the remaining nitrogen from conduit 166 which enters the liquefier as a gas at approximately −199° F. and 450 p. s. i. g. and leaves the liquefier as liquid at −271° F. Nitrogen gas leaves liquefier 164 by way of conduit 180 at −238° F. and 85 p. s. i. g., and flows to passage 198 in unit 128 of the second-named heat exchanger.

Reference is made again to connection 62 and the fact that a portion (18%) of the gas in connection 62 is tapped off for liquefier 164, going by way of conduits 176 and 178. The remainder of the gas in connection 62 passes to the unit 24 of heat exchanger 18, at −282° F. and 87 p. s. i. g. In unit 24, the gas gives up its refrigeration to supply part of the refrigeration which is lost by the removal of liquid oxygen. Secondary circuit nitrogen gas leaves unit 24 by way of two conduits 194 and 196. Conduit 196 connects with passage 198, and secondary circuit nitrogen leaves unit 24 of heat exchanger 18 at −165° F. and 86 p. s. i. g. The remainder (82.3%) of the gas from unit 24 passes to units 22 and 20 by way of conduits 194 and 204 respectively, leaving the unit 20 by way of conduit 206 at 103° F. and 81 p. s. i. g. Conduit 206 joins conduit 202 at 207.

Liquid nitrogen from liquefier 164 leaves by conduit 170 at −271° F. and 450 p. s. i. g., and undergoes substantially isenthalpic expansion in expansion valve 171, entering the column as a mixture of gas and liquid by way of the secondary circuit inlet connection 60 at −282° F. and 87 p. s. i. g. The liquid nitrogen thus put into the column supplies additional refrigeration for the column. An equal quantity of gaseous nitrogen leaves the column as aforesaid at −282° F. and 87 p. s. i. g. by way of secondary circuit column outlet connection 62, check valve 174, and conduit 172.

As raw air passes through the conduit 26 and the appropriate passages in units 20, 22 and 24 of heat exchanger 18, it is cooled by nitrogen from the column passing through other passages in units 24, 22 and 20, leaving heat exchanger 18 by way of conduit 74. After a time lapse of approximately two and one-half minutes, valve 14 is reversed. This reversal may be accomplished in any desired way, as for example by a cam connected to be driven by the compressor motor. Reversal of valve 14 as shown diagrammatically merely constitutes turning the valve through 90°. Entering raw air thereupon switches from the conduit 26 to the conduit 74, and of course enters the system by way of the passages which have just been used by the outgoing nitrogen. Conversely, the outgoing nitrogen passes outward through heat exchanger 18 in the passages which have just been used by the inflowing air.

The inflowing air during its passage through conduit 26 and the connected passages in heat exchanger 18 leaves its water and carbon dioxide in the form of deposits in the heat exchanger 18. Those impurities are carried out by the effluent nitrogen during the next part of the cycle in which the effluent nitrogen is in the passages which were just occupied by inflowing air. Thus, the raw air deposits its water, carbon dioxide, and other impurities in certain passages

of heat exchanger 18 during one portion of the cycle which lasts about two and one-half minutes, after which the air and nitrogen passages are interchanged, and during the next portion of the cycle lasting also approximately two and one-half minutes, the nitrogen sweeps out the impurities.

The reversing check valve 32 operates in such a manner as to prevent mixture of the inflowing air and effluent nitrogen. Thus, in the position of the parts shown in Fig. 1, the chamber 40 is at approximately 87 p. s. i. g. while the chamber 38 is approximately at column pressure (7 p. s. i. g.). The column pressure is so much less than the pressure of the inflowing air that the inflowing air easily holds valve 46 on its seat and prevents communication between chambers 38 and 40. Similarly, valve 44 is held on its seat by the difference in pressure between the inflowing air and the effluent nitrogen, so that there is no communication between chambers 36 and 42.

After the valve 14 is turned through 90°, air under pressure is admitted to the chamber 42 and holds valve 48 tight on its seat, thus preventing communication between chambers 42 and 38. At the same time, air flows into chamber 36 by lifting valve 44 off its seat and the air pressure in chamber 36 serves to hold valve 43 on its seat and prevents communication between chambers 36 and 40.

The method of air separation thus involves cooling the compressed air in the reversing heat exchanger 18 by heat exchange with at least one of the products of rectification, the product in this case being the effluent waste gases (largely nitrogen). The cooling referred to effects deposition in the reversing exchanger 18 of the impurities, mostly water and carbon dioxide. The passages carrying effluent waste gases and inflowing air are periodically alternated in order that the effluent waste gases may carry off the accumulated deposits of impurities, thus periodically purging or cleaning out the heat exchanger and preventing the accumulation of deposits of impurities which would otherwise clog the heat exchanger.

The compressed air is further cooled by heat exchange with the same product, namely effluent waste gases (largely nitrogen), this cooling taking place in the heat exchanger 226. The mixture is then passed to the column and is rectified therein. The rectification of the air in the double column will be well understood by those skilled in the art and need not be detailed here.

A gas rich in the aforesaid one product (nitrogen) is compressed in the compressor 112, and is cooled in a second heat exchanger 126, 128 by heat exchange with expanded gas. At least a portion of the thus cooled gas is divided into two streams. Thus, the portion leaving section 134 of unit 128 of the second heat exchanger in conduit 166 is divided, a portion of the gas continuing through the filter 168 on to liquefier 164 and the remaining portion branching off by way of conduit 162 to the expansion cylinder 138. If it be assumed for the time being that all the expansion to do external work is accomplished in one cylinder, it will be seen that the gas after expansion leaves the cylinder 138 by way of conduit 176. Thus, one of the aforesaid two streams passes to the expansion engine and is expanded with the performance of external work, while the other portion, namely the portion of gas continuing on in conduit 166 to liquefier 164, is liquefied by heat exchange with expanded gas from the

cylinder 138 passing to liquefier 164 by way of conduits 176 and 178.

Liquid nitrogen passes from liquefier 164 by way of conduit 170 and is expanded substantially isenthalpically through the expansion valve 177 and passes on to the column by way of the connection 60.

The stream of nitrogen passing into the column by way of connection 60 is mixed liquid and gas. A stream of gaseous nitrogen is withdrawn from the column by way of the connection 62 and passes to the conduit 176 by way of check valve 174, entering the conduit 176 at the intersection 192.

The stream of expansion engine exhaust returns to the compressor inlet 122 by way of the liquefier 164 and the second-named heat exchanger, and the withdrawn stream of gas leaving the column by way of the outlet connection 62 divides and passes into the stream of expansion engine exhaust by way of conduit 178 and passes to heat exchanger 18 by way of conduit 176.

More specifically, in the embodiment of the invention shown in Fig. 1, the secondary circuit nitrogen is expanded isentropically at three levels, namely in the three-stage expansion engine having cylinders 142, 140 and 138. The exhaust from the first stage 142 returns to the compressor inlet by way of a portion of the second heat exchanger 126, 128 and heps to further cool the remaining gas passing to the second and third stages of the expansion engine. The exhaust from the second stage passes through a greater portion of the second heat exchanger and additionally cools the remainder of the gas passing to the third stage. Finally, the engine exhaust from the third stage passes to the liquefier 164 and thus through the second heat exchanger. Secondary circuit nitrogen also supplies additional refrigeration to heat exchanger 18, by way of liquefier 164, conduit 170, the column, and conduits 172 and 176.

Thus the secondary circuit provides a refrigerant, namely liquid nitrogen and cold gaseous nitrogen, to supply refrigeration to the system which is lost by the fact that oxygen is taken from the system in the liquid form.

Oxygen withdrawn by the opening of valve 190 leaves the line 98 by way of subcooler 104 and is thus subcooled to some extent to minimize loss of oxygen product in storage.

The foregoing description of the operation presumes equilibrium operating conditions. The description of the operation for starting up a warm unit will now be described. To start up and cool a warm unit, the normally closed valves 186 and 190 are kept open, and normally open valve 177 is closed.

Compressed air is supplied by the air compressor 4, and enters the system in the usual manner, passing into the lower column by way of conduit 64 and air inlet 54. The compressed warm air leaves the column by way of connection 62 and passes through check valve 174 and conduit 172 into the conduit 176, whence it passes through conduit 188 by way of valve 190, which is now open. The compressed air then passes into conduit 180, closing the check valve 182. Air flows in conduit 180 to passage 198, thus flowing through the unit 128, through conduit 200, unit 126 and conduit 202 to the inlet 122 of the nitrogen compressor 112. The nitrogen compressor is now handling air.

Air is compressed in the nitrogen compressor to approximately 450 p. s. i. g., and passes to the three stages of the expansion engine 136. The expansion in the three cylinders 142, 140 and 138 is substantially the same as during normal operation, except that expansion in cylinder 138 takes place over a greater range than during equilibrium operation. With valve 177 closed and valve 186 open, the exhaust of the third cylinder or stage 138 is connected to nearly atmospheric pressure by way of conduits 176 and 178, liquefier 164, conduits 180, 184 (valve 186 being open) and 66, subcooler 104, heat exchanger 226, conduit 228, reversing valve 32, conduit 68, the reversing heat exchanger 18, and out to atmosphere by way of conduit 74, for the position of the valves 14 and 32 shown in Fig. 1.

The indicated expansion to a lower pressure (substantially atmospheric) of the third stage 138 of the expansion engine provides greater refrigeration than would be provided if the third stage were allowed to expand only to the pressure normally existing during equilibrium operation.

At the same time that air leaves the column by way of secondary circuit outlet connection 62, air also flows into the upper column by way of conduits 78 and 52, through expansion valves 82 and 94 respectively, and out by way of effluent line 66.

The system operates in the manner indicated, quickly cooling down the various pieces of warm apparatus, until liquid begins to accumulate in the column. When liquid begins to accumulate in the column, the composition of the secondary circuit gas changes gradually from substantially air to substantially nitrogen, the composition of this secondary circuit gas being ultimately the same as the composition of the gas above the nitrogen shelf of the lower column. Thus the composition of the secondary circuit gas will be substantially 98% nitrogen with about 2% of oxygen present.

The operator watches the liquid level in the boiler-condenser in the middle of the double column by means of a liquid level gage, not shown. When he sees that the liquid has attained a predetermined level (which will be such as to cover the nitrogen coils in the boiler-condenser), he closes valves 190 and 186, and opens valve 177. The apparatus is then in condition for normal operation, although it may take another short time period of from five to fifteen minutes to get the apparatus in complete condition for the production of oxygen of maximum purity. The normal or equilibrium operation of the apparatus is set forth above.

Reference is now made to Fig. 2 for a description of the normal operation of the embodiment of the invention shown therein. Compressed air enters heat exchanger 318 through the reversing valve 314 at substantially 110° F. and 88 p. s. i. g. Air leaves heat exchanger 318 by way of reversing check valve 332 and conduit 530 on its way to liquefier 464 at substantially —250° F. Air leaves liquefier 464 by way of conduit 364 and goes into the bottom of the column at —275° F. and 87 p. s. i. g.

Nitrogen effluent leaves the column from the connection 353 at approximately —314° F. and 7 p. s. i. g. With the valve 486 closed, the nitrogen goes into liquefier 464 (through passage 505) and leaves liquefier 464 by way of conduit 507 at substantially —275° F. The nitrogen effluent passes by way of reversing check valve 332 to passage 369 of heat exchanger 318, entering passage 369 at substantially the aforesaid —275° F.,

and leaves exchanger 318, discharging to atmosphere at approximately 104° F.

If oxygen product is taken from the apparatus in the liquid form, it may be removed by way of the tap 398 at substantially —290° F. If desired, of course, the oxygen may be pumped to storage under pressure, as shown in the embodiment of Fig. 1. If oxygen is taken from the system in the gaseous form, it comes from the column through the vertical stack portion 406 and conduit 509 at —290° F. and 7 p. s. i. g. The oxygen passes through liquefier 464 (passage 511 thereof), giving up its refrigeration to the incoming air, and leaving liquefier at —262° F. The oxygen then passes through passage 515 of reversing heat exchanger 318 and leaves by way of a gaseous oxygen connection 517 at 104° F.

Passing now to the secondary circuit of the embodiment shown in Fig. 2, compressed nitrogen enters the heat exchanger 428 at 110° F. and 200 p. s. i. g. Nitrogen leaves heat exchanger 428 by way of conduit 462 at —237° F. and 200 p. s. i. g. During normal or equilibrium operation, valve 471 will preferably be closed, or at most "cracked" open, so all or nearly all the nitrogen from heat exchanger 428 passes to the expansion engine, discharging from the expansion engine at —275° F. and 87 p. s. i. g. If valve 471 is kept open at all, a small amount (less than 5%) of the secondary circuit nitrogen is liquefied in 464. This liquid expands in valve 471 and goes to the column by way of connection 360 as a gas and liquid mixture.

The expansion engine exhaust passes by way of conduit 476, check valve 483, and conduit 478 to liquefier 464, passing through passage 479 of liquefier 464 and leaving the liquefier at —268° F., and passing at that temperature to the passage 498 in heat exchanger 428. The portion of the expansion engine exhaust which passes through liquefier 464 and then through the full length of passage 493 in heat exchanger 426 is approximately 88% of the total expansion engine exhaust. The remainder, approximately 12%, continues on and passes through the cold end of reversing heat exchanger 318, namely passage 477, leaving the cold end of heat exchanger 318 by way of conduit 496 at —163° F., and going at that temperature into heat exchanger 428 where it joins with the other expansion engine exhaust in passage 498. Nitrogen leaves the exchanger 428 by way of conduit 502 and enters the compressor inlet 422 at 104° F.

Make-up gas, if required, is supplied to the secondary circuit by way of connection 362. If the unit is operated with valve 471 closed, such make-up will be only what is needed to replace gas lost through leaks. If valve 471 is open during normal operation, the weight of gas passing through it must be replaced by an equal weight passing through connection 362.

The method practiced in the apparatus in Fig. 2 thus involves cooling the compressed air in the reversing heat exchanger 318 by heat exchange with at least one of the products of rectification, that product being the effluent waste gases (largely nitrogen) when oxygen is taken from the system as a liquid. When oxygen is taken as a vapor product, the inflowing air is cooled also by the outflowing oxygen product.

The cooling referred to effects deposition from the air in the reversing exchanger 318 of the impurities, mostly water and carbon dioxide. The passages carrying effluent waste gases and inflowing air are periodically alternated in order that the effluent waste gases may carry off the accumulated deposits of impurities, thus periodically purging out the heat exchanger and preventing the accumulation of deposits of impurities which would otherwise clog the heat exchanger.

The compressed air is further cooled in liquefier 464 by heat exchange with the same product or products depending upon whether oxygen is taken out as a liquid product or a vapor product. Furthermore, however, the inflowing air is also cooled in liquefier 464 by a large percentage of the nitrogen exhaust from the expansion engine, this nitrogen being secondary circuit nitrogen. The air mixture leaves liquefier 464 with very little liquid in it and passes into the column by way of conduit 364 and air inlet 354 in the condition of a saturated vapor with a very small percentage by volume of liquid. The percentage of liquid by weight entering the column by way of inlet 354 will normally probably not exceed 6%, so it will be seen by those skilled in the art that the percentage of liquid by volume is almost negligible.

The air is rectified in the double column 350 in a manner which is well understood by those skilled in the art and need not be detailed here.

The gas circulating in the secondary circuit, after normal equilibrium operations have been established, is rich in the nitrogen product; is in fact substantially the same composition as the gas in equilibrium with the liquid on the nitrogen shelf of the lower column. This gas may contain as much as 2% of oxygen, and is compressed in compressor 412, after which it is cooled in a second heat exchanger 428 by heat exchange with expanded gas returning to the compressor.

The cooled gas leaving heat exchanger 428 passes to the expansion engine 436 where it expands in doing external work. The thus expanded gas is used to refrigerate the liquefier and also the cold end of the reversing heat exchanger 318, as well as cooling the compressed nitrogen from the compressor 412. It will be noted that the secondary circuit is at all times connected with the nitrogen shelf of the lower column by way of the secondary circuit column outlet connection 362 and conduit 472. Thus, the secondary system is always ready to be replenished by make-up gas from the nitrogen shelf.

The description of the operation of the embodiment shown in Fig. 2 during the cool-down period will now be discussed. For cooling down the warm apparatus after a shut-down, normally open valves 382 and 394 are closed, while valves 471 and 486 are opened. Compressed air thus enters the system from the air compressor 304, passing through the reversing heat exchanger 318 and into the column by way of conduit 364 and inlet 354. The compressed air leaves the lower column by way of conduit 362, passing through conduits 472 and 476 to the nitrogen compressor inlet by way of liquefier 464 and heat exchangers 318 and 428.

The air is compressed in the nitrogen compressor, is cooled in heat exchanger 428, and divides; one branch passes to the expansion engine 436 and the other through liquefier 464 to the column by way of the conduit 470, expension valve 471, and connection 360.

With by-pass valve 486 open, expansion engine exhaust passes to the effluent line 366 through valve 486, and out to the atmosphere, cooling down exchangers 464 and 318. The cooling is

regenerative, until ultimately liquid accumulates in the nitrogen shelf immediately below the boiler-condenser in the middle of the column. This liquid overflows and falls to the bottom of the lower column.

As soon as it is observed by the liquid level gage (not shown) that the liquid in the bottom of the column has reached a predetermined level, valves 471 and 486 will be closed, and valves 382 and 394 will be opened, and the apparatus is ready for normal operation, except that it may take up to fifteen minutes of additional operation, while rectification gets started in the upper column, for the apparatus to produce the desired purity of oxygen.

As to both of the embodiments, namely that shown in Fig. 1 and that shown in Fig. 2, it may be pointed out that there is considerable flexibility possible in the operation of the secondary circuit. The quantity of nitrogen circulated in the secondary circuit can be varied. If the secondary circuit is operated at a low pressure, more nitrogen will be circulated. On the other hand, if the secondary circuit is operated at a higher pressure, it may be operated with the circulation of a lesser quantity of nitrogen.

As to the embodiment shown in Fig. 2, it may be pointed out that the high pressure of 200 p. s. i. g. for the nitrogen in the secondary circuit is contemplated for the production of liquid oxygen. If gaseous oxygen is produced, the unit may be operated at a lesser high pressure in the secondary circuit—on the order of 160 p. s. i. g.

Further as to the embodiment shown in Fig. 2, it will be understood by those skilled in the art that, during operation with valve 471 fully closed, the member 464 will serve as a "liquefier" only as to a very small quantity of the entering air. Under such circumstances, member 464 may more properly be termed a third heat exchanger.

While there are in this application specifically described two forms which the invention may assume in practice, it will be understood that these forms of the same are shown for purposes of illustration, and that the invention 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 a method of separating a gaseous mixture into its components, wherein the compressed gaseous mixture is rectified in a rectification column, the improvement comprising: cooling the compressed gaseous mixture in a first heat exchanger by heat exchange with at least one of the products of rectification, passing the mixture to the column for rectification therein, compressing a gas rich in said one product in a compressor, cooling said compressed gas in a second heat exchanger by heat exchange with expanded gas, dividing at least a portion of the thus cooled gas into two streams, passing one of said two streams to an expansion engine, expanding said one stream with the performance of external work, liquefying the other of said two streams in a liquefier by heat exchange with expanded gas, passing the thus liquefied stream to the column, dividing the stream of expansion engine exhaust, passing a portion of the exhaust to the compressor by way of the liquefier and the second heat exchanger, passing another portion of the exhaust to the compressor by way of a passage in at least the cold end of the first heat exchanger, withdrawing a stream of gas in the vapor state from the column, and passing the withdrawn stream of gas into the expansion engine exhaust.

2. In a method of separating a gaseous mixture into its components, wherein the compressed gaseous mixture is rectified in a rectification column, the improvement comprising: cooling the compressed gaseous mixture in a first heat exchanger by heat exchange with at least one of the products of rectification, passing the mixture to the column for rectification therein, compressing a gas rich in said one product in a compressor, cooling said compressed gas in a second heat exchanger by heat exchange with expanded gas, dividing at least a portion of the thus cooled gas into two streams, passing one of said two streams to an expansion engine, expanding said one stream with the performance of external work, liquefying the other of said two streams in a liquefier by heat exchange with expanded gas, passing the last-named stream to the column, passing the expansion engine exhaust to the compressor by way of the liquefier and the second heat exchanger, withdrawing a stream of gas in the vapor state from the column, dividing said withdrawn stream into at least two portions, separately warming said two portions by heat exchange with separate heat sources, further warming at least a part of said two portions by heat exchange with compressed gas, and finally passing all of the withdrawn stream to the compressor for compressing as aforesaid.

3. A method as in claim 2, in which one of said portions is warmed before compressing by heat exchange with compressed gaseous mixture.

4. In a method of separating a gaseous mixture into its components, wherein the compressed gaseous mixture is rectified in a rectification column, the improvement comprising: cooling the compressed gaseous mixture in a first heat exchanger by heat exchange with at least one of the products of rectification, passing the mixture to the column for rectification therein, compressing a gas rich in said one product in a compressor, cooling said compressed gas by heat exchange with expanded gas, dividing the thus cooled gas into two streams, passing one of said two streams to a first expansion engine, expanding said one stream in said first expansion engine with the performance of external work, warming the thus expanded gas by heat exchange with compressed gas, further cooling the remaining stream of thus cooled gas by further heat exchange with expanded gas, dividing the thus further cooled compressed gas into two streams, passing one of said two streams of further cooled gas to a second expansion engine, expanding said one stream of further cooled gas in the second expansion engine with the performance of external work, warming said stream of further cooled expanded gas by heat exchange with compressed gas, still further cooling the remaining stream of further cooled gas by still further heat exchange with expanded gas, dividing the still further cooled gas into two streams, expanding one of said streams of still further cooled gas in a third expansion engine with the performance of external work, warming the thus expanded stream of still further cooled gas by heat exchange with the remaining stream of still further cooled gas, further warming the still further cooled stream of expanded gas by heat exchange with compressed gas, passing all of the warmed streams of expanded gas back to

the compressor, liquefying said remaining stream of still further cooled gas by the aforesaid heat exchange with the stream of expanded gas from the third expansion engine, and using the liquefied stream of gas to provide needed refrigeration in the separation process.

5. Apparatus for separating air into an oxygen product and another product, comprising: a source of air under pressure; a reversing valve; first-named conduit means connecting said source with said valve; at least one reversing heat exchanger having two reversing fluid passages; second-named conduit means connecting the valve with one reversing passage of said heat exchanger; a second reversing valve; third-named conduit means connecting said one reversing passage of the heat exchanger with the second reversing valve; a rectification column having at least an air inlet, two product outlets, and secondary circuit inlet and outlet connections; means, including fourth-named conduit means, to connect the second reversing valve with the column air inlet; means, including fifth-named conduit means, to connect one of the column product outlets with the second reversing valve; sixth-named conduit means to connect the second reversing valve with the other one of the reversing passages of the heat exchanger; seventh-named conduit means to connect said other one of the reversing passages of the heat exchanger with the first-named reversing valve; a product outlet connected to the first-named reversing valve; a secondary circuit compressor having inlet and discharge connections; a second-named at least one heat exchanger having two fluid passages; means, including first-named secondary circuit conduit means, to connect the discharge connection of the secondary circuit compressor with one passage of the second-named heat exchanger; means to expand an elastic fluid with the performance of external work; means, including second-named secondary circuit conduit means, to connect said one passage of the second-named heat exchanger with the fluid expanding means to supply fluid thereto; a liquefier having two fluid passages therethrough; means, including third-named secondary circuit conduit means, to connect the second-named secondary circuit conduit means with one passage of the liquefier; a liquid conduit connecting said one passage of the liquefier with said column secondary circuit inlet connection; means to conduct expanded fluid from the fluid expanding means to the compressor inlet connection, said means including the other passage of the liquefier and the other passage of the second-named heat exchanger; means, including fourth-named secondary circuit conduit means, to connect said column secondary circuit outlet connection with said expanded fluid conducting means; and other means to conduct expanded fluid from the fluid expanding means to the compressor inlet connection, said means bypassing the liquefier and including at least a portion of one passage in the second-named heat exchanger.

6. Apparatus as in claim 5, in which the means to expand an elastic fluid comprises an expansion engine having a plurality of cylinders of which only one exhausts to the liquefier.

7. Apparatus as in claim 5, in which the means to expand an elastic fluid comprises an expansion engine having a plurality of cylinders, all of the cylinders being connected to receive fluid at substantially secondary circuit compressor discharge pressure and to exhaust fluid at substantially secondary circuit compressor inlet pressure.

8. Apparatus as in claim 7, in which the several cylinders are connected to expand fluid through different temperature ranges.

9. Apparatus as in claim 5, in which the means to expand an elastic fluid comprises an expansion engine having a plurality of cylinders connected to expand fluid through different temperature ranges.

10. Apparatus for separating air into an oxygen product and another product, comprising: a source of air under pressure; a reversing valve; first-named conduit means connecting said source with said valve; at least one reversing heat exchanger having two reversing fluid passages and a third passage, the third passage lying in at least the cold end of the reversing heat exchanger; second-named conduit means connecting the valve with one reversing passage of said heat exchanger; a second reversing valve; third-named conduit means connecting said one reversing passage of the heat exchanger with the second reversing valve; a rectification column having at least an air inlet, two product outlets, and secondary circuit inlet and outlet connections; means, including fourth-named conduit means, to connect the second reversing valve with the column air inlet; means, including fifth-named conduit means, to connect one of the column product outlets with the second reversing valve; sixth-named conduit means to connect the second reversing valve with the other one of the reversing passages of the heat exchanger; seventh-named conduit means to connect said other one of the reversing passages of the heat exchanger with the first-named reversing valve; a product outlet connected to the first-named reversing valve; a secondary circuit compressor having inlet and discharge connection; a second-named at least one heat exchanger having two fluid passages; means, including first-named secondary circuit conduit means, to connect the discharge connection of the secondary circuit compressor with one passage of the second-named heat exchanger; an expansion engine having intake and exhaust ports; means, including second-named secondary circuit conduit means, to connect said one passage of the second-named heat exchanger with the intake port of the expansion engine; a liquefier having two fluid passages therethrough; means, including third-named secondary circuit conduit means, to connect the second-named secondary circuit conduit means with one passage of the liquefier; a liquid conduit connecting said one passage of the liquefier with said column secondary circuit inlet connection; means to connect the expansion engine exhaust port with the compressor inlet connection, said means including the other passage of the liquefier and the other passage of the second-named heat exchanger; means, including fourth-named secondary circuit conduit means, to connect the secondary circuit column outlet connection with the last-named means; means to connect the secondary circuit column outlet connection with the third passage of the reversing heat exchanger; and means to connect said third passage with the secondary circuit compressor inlet connection.

11. Apparatus for separating air into an oxygen product and another product, comprising: a source of air under pressure; a reversing valve; first-named conduit means connecting said source with said valve; at least one reversing heat exchanger having two reversing fluid passages and a

third passage, the third passage lying in at least the cold end of the reversing heat exchanger; second-named conduit means connecting the valve with one reversing passage of said heat exchanger; a second reversing valve; third-named conduit means connecting said one reversing passage of the heat exchanger with the second reversing valve; a rectification column having at least an air inlet, two product outlets, and secondary circuit inlet and outlet connections; means, including fourth-named conduit means, to connect the second reversing valve with the column air inlet; means, including fifth-named conduit means, to connect one of the column product outlets with the second reversing valve; sixth-named conduit means to connect the second reversing valve with the other one of the reversing passages of the heat exchanger; seventh-named conduit means to connect said other one of the reversing passages of the heat exchanger with the first-named reversing valve; a product outlet connected to the first-named reversing valve; a secondary circuit compressor having inlet and discharge connections; a second-named at least one heat exchanger having two fluid passages; means, including first-named secondary circuit conduit means, to connect the discharge connection of the secondary circuit compressor with one passage of the seond-named heat exchanger; means to expand an elastic fluid with the performance of external work; means, including second-named secondary circuit conduit means, to connect said one passage of the second-named heat exchanger with the fluid expanding means to supply fluid thereto; a liquefier having two fluid passages therethrough; means, including third-named secondary circuit conduit means, to connect the second-named secondary circuit conduit means with one passage of the liquefier; a liquid conduit connecting said one passage of the liquefier with said column secondary circuit inlet connection; means to conduct expanded fluid from the fluid expanding means to the compressor inlet connection, said means including the other passage of the liquefier and the other passage of the second-named heat exchanger; means, including fourth-named secondary circuit conduit means, to connect said column secondary circuit outlet connection with said expanded fluid conducting means; other means to conduct expanded fluid from the fluid expanding means to the compressor inlet connection, said means by-passing the liquefier and including at least a portion of one passage in the second-named heat exchanger; means to connect the column secondary circuit outlet connection with the third passage of the reversing heat exchanger; and means to connect said third passage with the secondary circuit compressor intake.

12. Apparatus for separating a gaseous mixture into a desired product and waste gases, comprising: a source of compressed gaseous mixture, a reversing heat exchanger, and a rectification column connected in a rectification circuit; a fluid compressor, a heat exchanger, fluid expanding means, and a liquefier connected in a refrigeration circuit; means to conduct liquid from the liquefier to the column; and means to conduct fluid from the column to the fluid compressor including a passage in the reversing heat exchanger.

13. Apparatus as in claim 12, in which the fluid expanding means comprises an expansion engine having a plurality of cylinders of which one is connected to exhaust to the liquefier.

14. Apparatus as in claim 12, in which the fluid expanding means comprises an expansion engine having a plurality of cylinders, all of the cylinders being connected to receive fluid at substantially fluid compressor discharge pressure and to exhaust fluid at substantially fluid compressor inlet pressure.

15. Apparatus as in claim 12, in which the fluid expanding means comprises an expansion engine having a plurality of cylinders connected to expand fluid through different temperature ranges.

16. Apparatus as in claim 12, in which the last-named means includes a conduit connected to conduct expanded fluid from the fluid expanding means to the compressor inlet.

17. Apparatus as in claim 12, in which the last-named means also includes a conduit connected to conduct expanded fluid from the fluid expanding means to the compressor inlet, said conduit having two parallel branches, one of which includes a passage in the liquefier and a passage in the second-named heat exchanger, and the other of which includes said passage in the reversing heat exchanger.

18. Apparatus as in claim 17, in which the two branches are joined at their downstream end in the aforesaid passage in the second-named heat exchanger.

19. Apparatus for separating a gaseous mixture into a desired product and waste gases, comprising: a source of compressed gaseous mixture, a reversing heat exchanger having a non-reversing passage through at least the cold end thereof, and a rectification column, connected in a rectification circuit; a fluid compressor, a heat exchanger, fluid expanding means, and a liquefier, connected in a refrigeration circuit; means to conduct liquid from the liquefier to the column; and means to conduct fluid from the column to the fluid compressor including the non-reversing passage in the reversing heat exchanger.

20. In a method of separating a gaseous mixture into its components, wherein the compressed gaseous mixture is rectified in a rectification column, the improvement comprising: cooling the compressed gaseous mixture in a reversing heat exchanger by heat exchange with at least one of the products of rectification to effect deposition in the heat exchanger of impurities, periodically alternating the flow of mixture and product to effect removal of the impurities from the heat exchanger, further cooling said mixture by heat exchange with said one product, passing the mixture to the column for rectification therein, compressing a gas rich in said one product in a compressor, cooling said compressed gas in a second heat exchanger by heat exchange with expanded gas, dividing at least a portion of the thus cooled gas into two streams, passing one of said two streams to an expansion engine, expanding said stream of gas with the performance of external work, liquefying the other of said two streams in a liquefier by heat exchange with expanded gas, passing the liquefied stream of gas to the column, withdrawing a stream of gas in the vapor state from the column, passing the stream of expansion engine exhaust to the compressor by way of means which include the liquefier and the second heat exchanger, dividing said withdrawn stream of gas into at least two streams, and passing the two streams of withdrawn gas into the stream of expansion engine exhaust at different points.

21. A method according to claim 20, in which

one of the two withdrawn streams is subjected to heat exchange with the compressed gaseous mixture before passing into the stream of expansion engine exhaust and the other of the two withdrawn streams joins the expansion engine exhaust just prior to passage of said exhaust through the liquefier.

22. In a method of separating a gaseous mixture into its components, wherein the compressed gaseous mixture is rectified in a rectification column, the improvement comprising: cooling the compressed gaseous mixture in a reversing heat exchanger by heat exchange with at least one of the products of rectification to effect deposition in the heat exchanger of impurities, periodically alternating the flow of mixture and product to effect removal of the impurities from the heat exchanger, further cooling said mixture by heat exchange with said one product, passing the mixture to the column for rectification therein, compressing a gas rich in said one product in a compressor, cooling said compressed gas in a second heat exchanger by heat exchange with expanded gas, passing the thus cooled compressed gas to an expansion engine, expanding the thus cooled compressed gas with the performance of external work, passing the expansion engine exhaust to the compressor in at least two streams, one of which passes to the compressor by way of a third heat exchanger and the second heat exchanger in series and the other of which passes to the compressor inlet by way of at least portions of the first heat exchanger and the second heat exchanger in series, withdrawing a stream of make-up gas rich in said one product in the vapor state from the column as needed, and passing the withdrawn stream of make-up gas into the stream of expansion engine exhaust.

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References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,830,157	De Baufre	Nov. 3, 1931
1,864,585	De Baufre	June 28, 1932
2,091,349	Bergman	Aug. 31, 1937
2,417,279	Van Nuys	Mar. 11, 1947
2,424,201	Van Nuys	July 15, 1947
2,460,859	Trumpler	Feb. 8, 1949
2,470,483	Gadwa	May 17, 1949
2,482,303	Van Nuys	Sept. 20, 1949
2,496,380	Crawford	Feb. 7, 1950
2,530,602	Dennis	Nov. 21, 1950

FOREIGN PATENTS

Number	Country	Date
468,212	Canada	Sept. 19, 1950