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APPLICATION FILED MAY 16, 1904.

**924,136.** **Patented June 8, 1909.**

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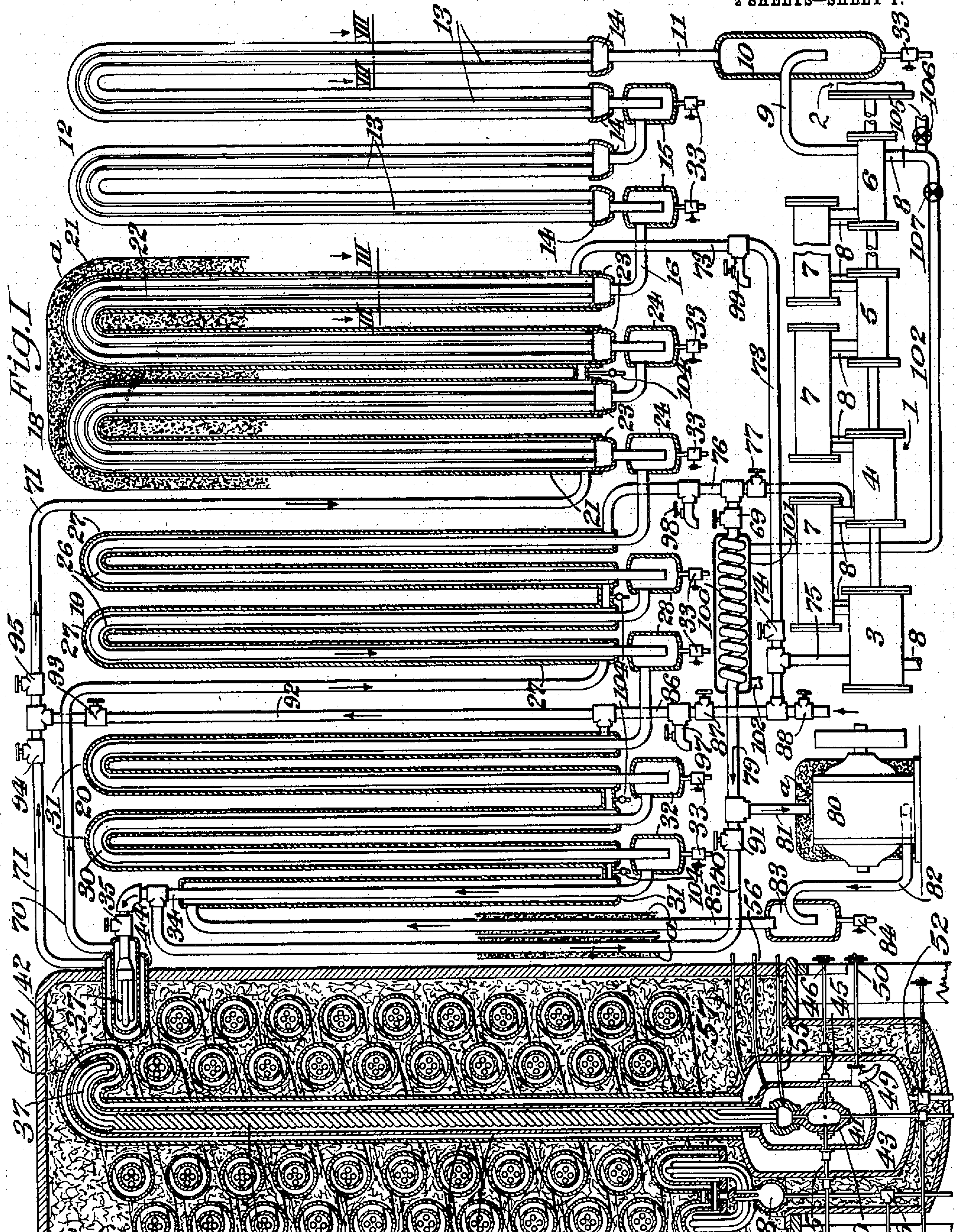


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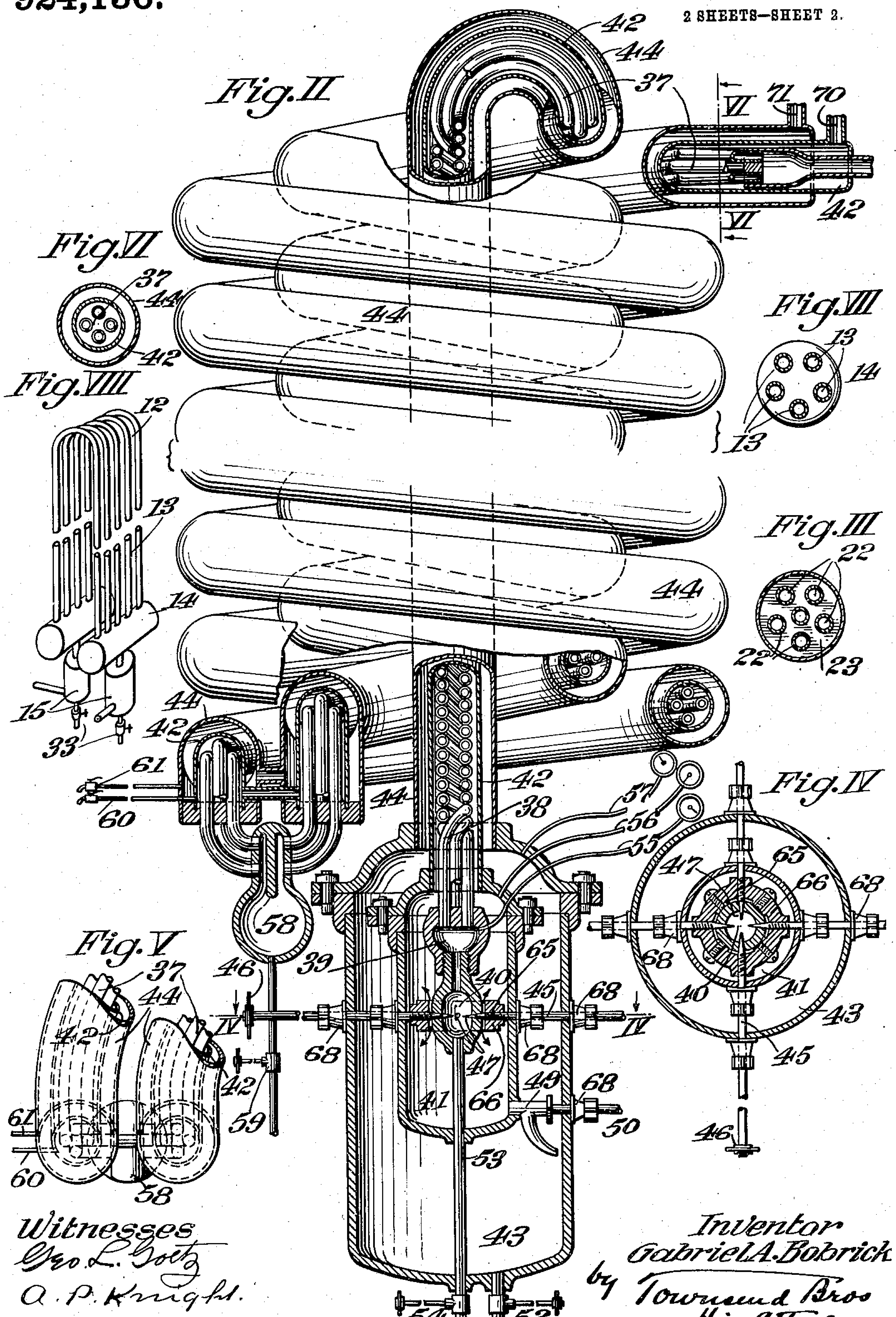


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# UNITED STATES PATENT OFFICE.

GABRIEL A. BOBRICK, OF LOS ANGELES, CALIFORNIA.

## PROCESS FOR THE LIQUEFACTION OF GASES AND SEPARATION OF AIR INTO COMMERCIAL OXYGEN AND NITROGEN.

No. 924,136. Specification of Letters Patent. Patented June 8, 1909.

Application filed May 16, 1904. Serial No. 208,096.

*To all whom it may concern:*

Be it known that I, GABRIEL A. BOBRICK, a citizen of the United States, residing at Los Angeles, in the county of Los Angeles and State of California, have invented new and useful Improvements in Processes for the Liquefaction of Gases and Separation of Air into Commercial Oxygen and Nitrogen, of which the following is a specification.

The primary object of my invention is to provide a process by which gases and mixtures of gases, having a low critical temperature (below zero Fahrenheit) such as oxygen, nitrogen, air, etc., can be liquefied in large quantities at a reasonable cost, and by which process the process of manufacturing the liquid gases, and particularly liquid air, can be made continuous, obviating the necessity of stopping at intervals for the sole purpose of thawing out and removing from the pipes of the liquefier the frozen particles of moisture and lubricating oil carried thereinto by the compressed air, or oil alone in the case of compressed gases free from moisture.

Another object of my invention is to enable a part of the air or gas to be used more than once in regenerative cooling, by a succession of expansions and temperature interchanges, thereby increasing the capacity and efficiency of the system, and a further object of the invention, in this connection, is to effect one of such expansions in a more efficient manner than is possible with free expansion, where the air upon expansion merely performs internal work. This result I obtain by causing one of said expansions to be effected adiabatically, or nearly so.

A further object of my invention is the provision for expansion separate from the liquefier, to effect, by temperature interchange, a preliminary cooling of the air or gas, in starting the apparatus, before such air or gas is allowed to enter the liquefier, to a point at which it will be practically free from oil and water, whereby deposition of either of the latter in the liquefier and clogging of the pipes therein, is avoided.

Another object of my invention is to provide for complete separation of carbon dioxid, oil, and aqueous vapor from the gas or air, in regular operation, before it is subjected to the adiabatic expansion above referred to, thereby preventing interference with the operation of the adiabatic expansion means, by any deposition of such substances therein in a frozen state.

A further object of my invention is to provide for complete abstraction from the air or gas of the heat remaining from the final compression in the compressor, without recourse to any cooling medium or agent other than the atmospheric air, thereby materially simplifying and cheapening the operation.

Another object of my invention is to so carry out the liquefaction that the expanded cold air or gas will act regeneratively to abstract heat to substantially its full capacity from all the compressed air or gas delivered by the compressor.

A further object of my invention is to provide for the practically complete precipitation, freezing out and removal from the compressed air, of moisture, vaporized oil, and part of the carbon dioxid, etc., by expanded air and without recourse to any other medium, such as ammonia, ice and salt, calcium chlorid, soda lime, etc., which either require a complicated and expensive system of ammonia compression and expansion machinery and apparatus, or a daily supply, charging and cleaning of vessels containing the ice and salt, calcium chlorid, etc.

Another object is to provide for the efficient separation of atmospheric air into commercial oxygen and commercial nitrogen within the expansion chambers without recourse to connections leading to or from the liquefying chamber, which conduct external heat into the same.

By commercial oxygen I mean a gas comparatively rich in oxygen and poor in nitrogen, while in commercial nitrogen, the opposite proportions obtain.

My invention in its entirety comprises a new process for the liquefication of air or gases and an apparatus for carrying out such process, but my present application is limited to the process, the apparatus referred to being set forth and claimed in another application, Serial No. 152,619, filed May 18, 1903.

To simplify the specification, I will describe the process as carried out in the manufacture of liquid air.

It is to be understood that the process may be used for liquefying air or any gas within the range of its capabilities and that the use in this specification of the terms air and gas is not intended as any limitation of the invention.

The accompanying drawings illustrate an apparatus suitable for carrying out my process.

Figure I is a view of such apparatus, showing the entire system, with the temperature interchanges and liquefier proper shown in section, and other parts diagrammatically. Fig. II is an enlarged partly sectional elevation of the upper and lower parts of the liquefier. Fig. III is a section on the line III—III in Fig. I of the first section of the fore-cooler or counter-current apparatus. Fig. IV is a horizontal section, in the line IV—IV in Fig. II of the free expansion device of the liquefier. Fig. V is a plan view of the lower end of the outer temperature-interchanging or counter-current pipes of the liquefier, near the junction of the outer and inner coils. Fig. VI is a transverse section on line VI—VI in Fig. II of such counter-current pipes. Fig. VII is a transverse section on line VII—VII in Fig. I of the pipe means for cooling the air or gas after the last compression and before it passes to the regenerative coolers. Fig. VIII is a perspective view of another form of such pipe means.

Referring to Fig. I, an air compressor is designated in a general way at 1, comprising power cylinder 2 and compression cylinders 3, 4, 5, 6, with intercoolers 7, all arranged in the usual manner. The cylinders are water-jacketed and water supply is circulated through such jackets and through the intercoolers, and discharged, by pipe connections 8. It will be understood that the number of stages in the compressor will depend on the pressure used, a four stage compressor, for example, being preferred for pressures above 2500 lbs. per square inch, such as are desirable in working this apparatus. From the high pressure cylinder 6 the compressed air is led by a pipe 9 to an oil and moisture trap 10, whence it passes by a pipe 11 to a cooler 12 for absorbing the heat remaining for final compression. Said cooler is preferably so constructed as to abstract this heat without recourse to cooling water or any cooling or heat abstracting agent or medium, other than the surrounding atmospheric air. It will be understood that for this purpose a more extended surface will be necessary than is required with a cooler using water as a heat absorbing medium. In order to make this cooler efficient and comparatively compact and inexpensive I prefer to construct the same with a plurality of tubes or conduits 13, each of relatively small diameter, thereby increasing the surface or area for transmitting heat. Moreover, from the accepted formula $t=\frac{pdf}{2Tc}$, in which, $t$=thickness of metal in inches, $p$ = pressure in lbs. per square inch; $d$=diameter of tube; $f$= factor of safety; T=tensile strength of metal; and $c$=coefficient; we know that for internal pressures we can reduce the thickness of the walls of tubes to one-half, one-quarter, etc., provided we reduce the diameter of the tubes to one-half, one-quarter, etc., and as the quantity of heat transmitted through a metal is inversely proportional to its thickness, it follows that for a strength of tube corresponding to a determined pressure, the smaller the tubes are in diameter, the greater will be the amount of heat transmitted from the interior to the outside. Moreover, owing to the small diameter of the tubes, the stream of air or gas passing therein is in more efficient heat transmitting relation with the walls thereof. In a large tube the central or axial part of the stream transmits practically no heat to the walls except by convection, and by reducing the diameter the amount of air thus protected or isolated from the walls is also reduced. By such a construction I am enabled to provide for complete abstraction of all the heat remaining from the final compression, without the use of a special cooling agent, such as water, and while the first cost of a cooler built on this principle may be equal to or greater than the cost of a water-circulating cooler there is a saving in running expenses on account of the saving in water used.

The number and length of pipes required in this cooler will depend upon the quantity of compressed air circulated or passed and the rapidity with which it flows through the pipes. In practice I have found that the highest temperature of the compressed air after leaving the last stage of the compressor is about 260° F., when operating with a four-stage water-jacketed compressor with intercoolers but no aftercooler, which compressor delivers about 1500 cubic feet (about 111 lbs.) per hour, of atmospheric air = about 7½ cubic feet of air, compressed to a pressure of about 3000 pounds to the square inch. To abstract the remaining heat of compression of this compressed air by radiation and contact through copper pipes with the surrounding atmosphere, it is necessary that about 10 square feet of internal surface should be provided in the pipe, requiring about 100 feet of tubing ¼ inch iron pipe size. These multiple conduits 13 terminate in headers 14 whereby connections may be made to the incoming and outgoing pipes. It will generally be found desirable to make this cooler in a plurality of sections arranged in series and each section will, as shown, be provided with headers at each end. It will be understood that these coolers, pipes or conduits may extend vertically, horizontally or in any desired direction, but in any case it will be necessary wherever there is an upward bend or low point in these conduits or in their connections to provide a trap whereby any liquid that may be condensed from the air passing therein will be collected and can be drawn off from time to time. Traps 15 are shown for these pipes in connection with the cooler 12 at points where the current of air or gas is reversed and caused to take an upward course.

One construction of this cooler is shown in Figs. I and VII, the pipes 13 being arranged in parallelism and extending from circular headers 14. To more fully expose the pipes 13 on both sides to the cooling action of the outer air, it may be desirable, in some cases, to construct the cooler as shown in Fig. VIII, the pipes 13 being arranged side by side and extending from parallel header tubes 14, so that each pipe 13 is fully exposed on both sides to radiation and contact with the outer air. The compressed air flowing through the pipes 13 of said cooler 12, which are exposed to the atmosphere, interchanges temperatures with the surrounding air and by the time the compressed air leaves said cooler all of the heat of compression is abstracted from it and it is approximately of the same temperature as the air in the room. Part of the moisture and oil contained in the air will condense in this cooler 12 and will be collected in, and from time to time, removed from the traps 15. From the cooler 12 the air passes by the pipe 16 into the counter-current apparatus called the fore-cooler associated with the liquefier proper. In order to perform the cooling action in this apparatus in the most efficient and convenient manner I find it desirable to divide such apparatus into a plurality of sections which will successively reduce the temperature of the air in the following manner.

The first section, indicated at 18, serves to reduce gradually the temperature of the compressed air to a stage approaching the freezing or solidifying point of water or aqueous vapors contained therein. The second section, indicated at 19, operates to further reduce the temperature of such compressed air to a point below the freezing or solidifying point aforesaid; while the third section, indicated at 20, serves to still further reduce the temperature of the compressed air to a point at which it is adapted to enter the liquefier proper, practically free from moisture and vaporized oil. The first section 18 is desirably constructed with multiple tubes or conduits 22 each of comparatively small diameter, as above described for cooler 12, thereby providing a maximum heat transferring effect between the gas flowing in these conduits and the surrounding medium. The outer envelop or conduit 21 surrounds these multiple tubes 22, as shown in Fig. III, and serves for the passage of a return current of cool air as hereinafter described. Headers 23 for these multiple pipes 22 are provided. Inasmuch as the compressed air is cooled in this section 18 to approximately the freezing point of water, it follows that there is no possibility of deposition of ice or snow in the pipes thereof and that the latter may be made of comparatively small diameter, as stated, without interfering with their regular and continuous operation. The greater part of the volatilized oil, however, is removed from the air in this section and collected in traps 24 which are placed at the lower-most points thereof to enable the oil and water to collect and be drawn off from time to time.

The next section 19 carries the refrigeration beyond the freezing point of water and it is, therefore, not desirable to provide such section with small pipes similar to those of sections 12 and 18 as the deposition of ice and snow therein would soon clog the pipes and interfere with the continuous operation, although in large plants comparatively large pipes arranged in multiples may be used. The internal pipe 26 of section 19 is, therefore, preferably a single conduit of relatively large diameter so as to allow considerable deposition of ice and snow on its inner walls without interfering with the free passage of compressed air therethrough. It will be understood that in the regular operation of the apparatus a considerably reduced amount of the aqueous vapor and oil will be contained in the compressed air when it reaches this section so that only a comparatively very thin coating of ice and snow will form on the inside walls of pipes 26, and part of this may be blown out from time to time during the operation of the plant, by opening the valves 33 of the traps 28. 27 designates the outer pipe or return current conduit of this section 19. The traps 28 are provided at the lower-most points of this section 19 to collect and allow removal of the condensed or solidified substance from time to time.

Section 20 is shown as similar in construction to section 19, having a single conduit 30 of relatively large cross-sectional area and an external or return current conduit 31, and traps 32 located at the lower-most points of the internal conduit.

All of the traps, 10, 15, 24, 28 and 32 are provided with draw off valves or cocks 33 to enable them to be blown out or cleaned from time to time.

From section 20 the compressed air passes by connection 34 and valve 35 to the liquefier 36. In regular operation the air has been cooled by the time it reaches the liquefier to such a point that it is practically or as near as it possibly can be done in practice, free from aqueous vapor and oil, and has also been relieved of part of its carbon dioxid. It is therefore practicable to construct the liquefier with multiple pipes or conduits for the passage of the compressed air, thereby obtaining the result above set forth of increased heat transmitting power. The internal conduit or high pressure passage means of the liquefier, therefore, desirably consists of multiple small pipes 37 which, in order to obtain a great length inside of a given space are desirably made as shown in the form of concentric helical coils, the conduit, for example, extending from the intake point or valve 35 in a descending helix and then upward in a helix arranged within the first helix and finally downward within the internal helix and substantially axial to both helices. Liquefiers have been made with multiples of small pipes, but in such cases calcium chlorid, ice and salt, or expanded ammonia, has been used for freeing the air from moisture, and soda lime has been used for freeing the air from carbon dioxid. To further increase the length of this piping, this downwardly extending portion thereof, indicated at 38, is desirably made in helical form as shown. At its lower end, this downwardly extending part of the pipes or conduits 37 terminates in a header 39, in which is screwed or secured the expansion valve-chamber, expander, or free expansion device 40. This valve device opens or discharges into an intermediate receiver or chamber 41, which at its upper end opens directly into the lower end of a return current casing, pipe or conduit 42, which extends up around the internal conduit portion 38 aforesaid, and surrounds and follows the helical direction of the internal pipes 37 as far as the valve 35. Inclosing this intermediate chamber or receiver 41 is an outer or low pressure chamber or receiver 43 which at its top opens directly into the lower end of an outer return casing, conduit or pipe 44, which extends upwardly outside of the intermediate pipe 42 and surrounds the pipes 37, 42 throughout their helical course, as far as the point where the conduit 37 enters the liquefier.

The valve, or valves, 45 having suitable operating means 46 control the passage, through the valve openings or seats 47, of the compressed air or liquid from the inner high pressure chamber 40 to the intermediate pressure chamber 41. A valve 49 and operating means 50 control the escape of the air or fluid from the intermediate chamber 41 to the outer chamber 43.

52 designates a valve or cock for drawing off the liquid or fluid from the outer chamber 43, and 53 designates a pipe leading downwardly from the inner high pressure chamber and controlled by the valve 54 for blowing out the internal conduit, to remove deposits.

Pipe connections or passages 55, 56 and 57 lead from the respective high pressure, intermediate pressure and low pressure chambers 40, 41 and 43 and are connected to suitable pressure gages to enable the attendant to determine the pressures in the respective chambers. A trap 58 is provided at the lowest point of the helical coils of the liquefier where the descending and ascending portions meet, to collect and enable the withdrawal of separated carbon dioxid, or any other deposit; this trap having an outlet controlled by a valve or cock 59.

Draw off valves or pet cocks 60, 61 are provided at the lower-most or junction points of the ascending and descending helical coils of the intermediate and low pressure return current pipes 42 and 44.

The entire system of piping of the liquefier is inclosed or embedded in suitable heat-insulating material indicated at 63, which in turn is inclosed in casing 64.

While I do not limit myself to any special construction of free expansion valve device, I have found the form shown in Figs. II and IV to be desirable, the same consisting of a plurality of needle valves each having a screw portion 65 adapted to engage a ring 66 surrounding and secured to the chamber 40 and the inner ends of the needle valve spindles being pointed and elongated so as to coöperate with the conical openings or valve-seats 47 and, when moved clear in, to protrude into the valve chamber 40 and thereby break through any frozen deposits that may have formed on the inner walls thereof near the openings. The valve spindles are provided with stuffing-boxes 68 where they pass through the walls of the intermediate and outer chambers 41 and 43.

From the return conduits 42 and 44 of the liquefier the expanded cold air is led by pipes 70 and 71 through the external conduits of the counter-current apparatus, above referred to. The pipe 71 from the low pressure conduit 44 of the liquefier leads to one end of the external conduit 21 in section 18 of the counter-current apparatus, connection being made from the other end of such conduit 21, through the pipe 73 and valve 74, to the intake pipe 75 of the compressor. The pipe 70 leads from the intermediate pressure conduit 42 of the liquefier to one end of the external pressure conduit 27 of section 19 of the counter-current apparatus. The third section 20 of the counter-current apparatus is desirably cooled by utilization of this same current of air that cools section 19. This air at the intermediate pressure, in passing through section 19, has absorbed so much heat that to enable it to be used in further cooling it is necessary to reduce its temperature by allowing it to expand. Such expansion may be performed in any suitable apparatus, but I prefer to provide for this purpose a thermodynamic engine or expansion device wherein the air is caused to perform external work in the act of expansion, as such a device is not only advantageous in utilizing a large percentage of the energy due to expansion but is also much more efficient in reducing the temperature than a free expansion device would be. The pressure of the air flowing through the high pressure pipes is, for instance, 4000 lbs. to the square inch, equal about 272 atmospheres, gage pressure. If it is expanded into receiver 41 to a gage pressure of, say, 60 lbs. to the square inch = about 4 atmospheres, then according to the well known formula of Joule and Thompson the drop in temperature due to internal work done by free expansion $= \frac{p_1 - p}{4}\left(\frac{289}{t_1}\right)^2$, $t_1$ being the absolute temperature in degrees centigrade, before expansion, and $p_1$, $p$ being the initial and final pressures in atmospheres. The thermal advantage which would be gained by expanding the compressed air at 273° C. absolute from 4000 lbs. to the square inch, to say atmospheric pressure, instead of expanding it to 60 lbs. gage pressure would be about the difference between 137° and 135° F. = 2° F., and as $t_1$ is lowered, this difference is increased, and at the point of liquefaction is equal to about 4° F., whereas by the adiabatic expansion of air of a gage pressure of 60 pounds to the square inch to atmospheric pressure, according to the formula of relations between pressures and temperatures, due to adiabatic expansion, $t = t_1\left(\frac{p}{p_1}\right)^{0.291}$, in which $t_1$ $p_1$ are the absolute temperature and pressure before expansion, and $t$ $p$ the absolute temperature and pressure after expansion; the drop in temperature, from say, 70° F., will equal about 199° F., (in practice about 185° F.), giving a final temperature of about −115° F. Besides this great gain in thermal advantage, about 50% of the work done in the compressor, while compressing this amount of air to a gage pressure of 60 pounds to the square inch, is recovered. The air that passes from the expansion engine to the final section 20 of the counter-current apparatus, may be assumed to have a temperature of about −115° F., and the compressed air that passes from the section 20 will, therefore, enter the liquefier at a little higher temperature, say from −50° F., to −75° F., so that it will not be possible for it to contain aqueous vapor or oil to an extent sufficient to interfere with the operation, it being understood that the temperature of the outgoing compressed air from section 20, will vary with the temperature of the incoming air and the proportion of the air in the outer conduit to that in the inner one. From two thirds to four-fifths of the total amount of air compressed and expanded passes thus through the return conduit 31 of section 20 and leaves the same at from 0° F., to −20° F., and it is then led through pipe 92 and valve 93 so as to join the balance of the air passing through pipe 71, which may be assumed to have a temperature of about −80° F. The combined quantity of air will then pass to section 18 so that all the air delivered by the compressor, except that which has been liquefied, or in any other way wasted by blowing out, etc., is utilized in cooling this section. The temperatures above given are only approximate.

Owing to the fact that the drop in temperature in such device performing external work follows more or less closely the law of adiabatic expansion, although it cannot be strictly termed such, for more or less heat will be transmitted by radiation and conduction, I term the same adiabatic expansion means. Such adiabatic expansion means may consist of any suitable thermodynamic engine, expansion engine, motor or turbine, which is herein indicated at 80. Connection is made by pipe 79 and valve 69 therein from the outgoing pipe 76 of the return conduit 27 of section 19 to the intake pipe 81 of this engine and from the exhaust side of the latter a pipe 82 leads to a trap 83 provided with a draw-off cock 84 and connected by a pipe 85 to one end of the external conduit 31 of section 20, the other end of said external conduit 31 being connected through a pipe 92 and valve 93 to the pipe 71, leading to the outer conduit of section 18, from which connection is made as above described to the low pressure compressor cylinder. Valves 94, 95, are provided in pipe 71, one on each side of the junction with pipe 92.

77 indicates a valve controlling a direct connection from pipe 76 to the intermediate compressor cylinder 4.

88 indicates a valve which controls communication from the intake pipe 75 to the outer air; this valve is a self regulating check valve set to a certain pressure so as to admit only the required amount of atmospheric air.

97, 98 and 99 designate draw-off valves or cocks communicating with pipes or conduits 86, 76 and 73 to enable the gaseous contents thereof to be withdrawn when desired.

Taps or cocks 104 are provided at the lowest points of the return conduits 21, 27 and 31 to draw off condensed substances which may accumulate. It will be understood that moisture will not deposit in these pipes except under unusual conditions.

In practice if operating with atmospheric air, a gas rich in nitrogen may be drawn off at cocks or valves 97 or 98, or a gas rich in oxygen may be drawn off from cock 99 as hereinafter explained. Connections may be made with gasometers, or other means for storing the gases for future use. 100 designates a heater or warmer that may be interposed in the connection 79 from pipe 76 to pipe 81 whereby the air that is delivered at intermediate pressure to the motor or expansion engine 80 may be warmed before expansion so as to increase the output of the engine, or not to permit too low a temperature therein. I prefer to keep the air entering the engine 80 at a temperature of about 70° F., although a lower or higher temperature may be maintained. This warmer or heater may absorb the heat from the surrounding atmosphere, or as shown may be provided with external casing 101 through which water or other medium is circulated by pipe connections 102, and the outlet of said casing may be connected with the water supply pipes 8 of the compressor, so as to utilize the same water for the compressor. A water supply pipe 105 and valves 106, 107 are provided for enabling the circulating water to be supplied to the compressor when the device 100 is omitted or not in use.

The mechanical energy developed by the motor or expansion engine 80 may be utilized in any suitable manner. It will be understood that the liquefier and the entire regenerative apparatus, including the cooler sections 18, 19 and 20 and their traps are properly protected from absorption of heat from the outer air by thorough insulation thereof in well known manner. The expansion engine 80 is also insulated, or protected from the heat of the outer air. To avoid confusion the insulating material *a* is mostly omitted from the views.

Before proceeding to describe the process as carried out in this apparatus the following explanation is desirable as to the general purpose thereof and the functions which the apparatus is required to perform for efficient operation. The process is designed to liquefy air or gases or mixtures of gases having a low critical temperature, (below zero F.) such as oxygen, nitrogen, air, etc., but to simplify the specification I will assume that the plant is used for the manufacture of liquid air. It must be understood, however, that the name "liquid air" is misapplied. Atmospheric air is a mechanical mixture of nearly 20.7% of oxygen and 79.3% of nitrogen by volume. It also contains about 0.04% of carbonic acid gas, the percentage varying with the location of the plant, and about 0.0012 pounds of aqueous vapor, or moisture, per cubic foot, at the point of saturation, at 70° F. The amount varies with the location of the plant and the conditions of the weather. Assuming the average relative humidity to be 75% at sea level, a cubic foot of air will contain about 0.0009 lbs. of aqueous vapor = about 1.22% by weight. Carbonic acid gas and aqueous vapor are the most troublesome elements in the manufacture of liquid air by the self-intensive and regenerative process owing to their tendency to condense and freeze in the pipes, forming a non-heat conducting coating on the inner walls of the pipes and finally clogging the pipes and valves preventing the further passage of the air. The product manufactured from atmospheric air by the process now in use contains from 25 to 35% of oxygen, from 65 to 75% nitrogen, but it is practically free from aqueous vapor or water in any of the three stages, gas, liquid or solid and unless means have been provided for the removal of the carbonic acid, the liquid contains almost 1% carbon dioxid, imparting to it a milky appearance.

The presence of an excess of oxygen and frozen carbon dioxid in the liquid can be readily explained. The air leaves the compressor approximately in the proportions above given for atmospheric air, with a mixture of oil used for lubricating the air cylinders. Practically all the moisture and the oil are precipitated and frozen within the pipes long before the air reaches its critical temperature. When the air begins to liquefy it drops into the receiver provided for it and in this receiver it is always in a state of ebullition. The boiling point of nitrogen at atmospheric pressure being about −318° F.; of oxygen about −294° F.; and of carbon dioxid about −112° F.; it follows that the product of evaporation is almost wholly nitrogen; a very small portion of the oxygen evaporates but none of the carbon dioxid, hence the liquid is comparatively rich in oxygen and carbon dioxid.

To construct and successfully and economically operate a plant for the manufacture of liquid air by the free expansion, accumulative, self-intensive or regenerative process, or for the manufacture of commercial gaseous oxygen and nitrogen which involves, first, the liquefaction of air and then its separation into commercial oxygen and nitrogen by fractional distillation; and to keep the liquefier in continuous operation, it is essential:—

First:—that the air should be compressed to as high a pressure as possible and expanded to a pressure sufficiently low, consistent with the economical operation of such system. I find that a pressure of about 4,000 lbs. to the square inch is most desirable, for the reason that the extra cost of compression, say from 2,500 lbs. to the square inch to 4,000 lbs. to the square inch, and the cost of removing the extra heat due to the higher compression, are negligible as compared to the advantages gained by high compression. The thermal advantages gained by high compression may be seen from the following:—The power required in compressing 100 cubic feet of atmospheric air per minute in a four stage compressor to 2,500 lbs. per square inch, equals about 39 horsepower, and the power required in compressing the same volume of air to 4,000 lbs. per square inch is about 41½ horsepower. Owing to the internal work done by the expansion of air from a pressure of 4,000 lbs. to the square inch and a temperature of 70° F., to say 60 lbs. to the square inch, the drop in temperature will equal about 135° F., and if expanded from 2,500 lbs. per square inch to 60 lbs. per square inch, the drop in temperature will equal about 82.5° F.; or on expansion from 4,000 lbs. per square inch we get a drop in temperature of 3.25° F., per horsepower, while on expansion from 2,500 lbs. per square inch we get a drop in temperature of 2.1° F. per horsepower. When the temperature of the air before expansion is lower than 70° F., the drop in temperature in both cases is proportionately greater.

Second:—that the air should be compressed by stages or separate operations, preferably four, and the heat of compression removed during and intermediate the successive stages. When atmospheric air is compressed to a pressure, of say, 3000 pounds to the square inch in a two-stage compressor, both water jacketed and with an intercooler between the two stages, there is, beside the greater amount of energy required in operating such compressor as compared with one of four-stages, neglecting the extra friction which is proportionately smaller in larger compressors, a constant danger of explosion from internal combustion, some cases of which have already been recorded.

Third:—that means should be provided for the total removal of the heat due to the last compression and before the compressed air enters the liquefier.

Fourth:—that the compressed air before entering the liquefier should, as nearly as practicable, be free from the aqueous vapor or moisture contained in the air and from the oil used in lubricating the cylinders of the compressor.

To practically free the air of the aqueous vapor and vaporized oil, its temperature should be reduced to about zero Fahr., or lower and, therefore, coolers capable of reducing the temperature to about zero Fahr., or lower, should be installed between the high pressure cylinder of the compressor and the liquefier, otherwise the aqueous vapor and the oil will freeze in the pipes of the liquefier. The pipes being small, any coating thus formed will be relatively thick and the ice and snow being a poor conductor of heat, they will seriously interfere with the proper interchange of temperatures; the irregular freezing of the water and oil in the small pipes will produce a rough surface within the pipes with the result that a large portion of the work done by the compressor will be lost in friction, and moreover, considerable heat will be thereby developed at the point where it is most objectionable. Finally the ice and snow will choke up the pipes and the liquefier will cease operation. In operating a liquefier with compressed air not freed from the moisture and vaporized oil, I have observed after several hours' run, a difference of nearly 400 lbs. to the square inch, between the pressure of the air in the pipe before entering the liquefier, and the pressure of the air in the expansion chamber before passing the expansion valve. When the air by previous cooling to the extent above stated, was freed from the moisture and oil present, the loss of pressure was found to be negligible in working with compressed air at from 1200 to 3500 lbs. to the square inch. Another important advantage arising from the separation of the aqueous vapor before it reaches the liquefier is that it saves considerable of the energy that would otherwise be expended in uselessly cooling the aqueous vapor to the low temperatures reached in the liquefier. Moreover, if the latent heat of the aqueous vapor is abstracted in the liquefier by the expanded air, it will warm the air at the very point where it is the least desirable. Also by separating the aqueous vapor to the full extent possible in practice, before it reaches the liquefier, I am enabled to extract its latent heat of vaporization and fusion by cooling means more economical than the free expansion devices of the liquefier.

In a 100 H. P. plant, compressing about 1073 lbs. per hour of atmospheric air to the pressure of 4000 lbs. to the square inch, the total weight of the aqueous vapor in an hour's supply of air will equal about 13 lbs., assuming the temperature of the air to be 70° F., and the relative humidity 75%, this amount of aqueous vapor will require, to cool it to the average temperature of the liquefier, say −190° F., the abstraction of about 17,400 H. U., and this will require about 226 lbs. of the expanded air to be used in abstracting heat from the aqueous vapor, or about 15% of the work done in the compressor will be used up in merely cooling the aqueous vapor. This amount will be considerably reduced if a trap with an outlet is provided at the lowest point or points of the cooler where the temperature of the air after the last compression is reduced to about that of the atmosphere, or that of the circulating water, if such a cooler is used.

Fifth:—As much as possible of the carbonic acid gas or carbon dioxid, should be removed from the compressed air before it reaches the liquefier, or before it reaches the expansion valves.

Sixth:—A trap or traps should also be located at any point or points in the liquefier where there is an upward bend or a junction of descending and ascending pipes.

Seventh:—All expansion and return current means must be thoroughly insulated from the heat of the outer atmosphere and the same is true of the pipes and traps carrying air at a temperature below 32° F., except at the outlets.

The operation of the apparatus, in producing liquid air according to this process may be described as follows:—Valve 88, admitting atmospheric air to the compressor will, in general, be open. In starting, valve 35 leading to the liquefier, will be closed, valve 91, admitting compressed air directly to the motor 80 from the last cooler section 20, will be opened. Valve 87 may be opened and valves 93, 74, 69 and 77 closed so as to deliver the exhaust from this motor through the external conduit of section 20, directly back to the compressor. Under these conditions only section 20 will be used in cooling. Atmospheric air will be drawn in through valve 88 and will be subjected to successive compressions in the cylinders 3, 4, etc., of the compressor, the heat due to compression being absorbed by the water jackets and intercoolers, up to the last stage, from which the compressed air is discharged in heated condition, only so much of the heat of the last compression having been absorbed as can be taken up by the water jacket of and radiated and conducted from the high pressure cylinder. From this cylinder the compressed air passes to the trap 10, where it parts with the oil carried over in a liquid form and also with part of the moisture, owing to the comparatively low temperature of said trap, and then passes through the preliminary cooler 12, wherein it interchanges temperatures with the surrounding atmosphere, and precipitates and deposits part of the oil carried with the air in a gaseous state and also part of the aqueous vapor.

When air containing aqueous vapor is cooled, the temperature of the vapor is lowered, with the result that its density is increased until the vapor reaches a maximum density for the corresponding temperature. If the temperature is still lowered, part of the vapor will condense; and if the cooling is gradual, and the flow of air is slow and takes place in vertical or inclined pipes provided with traps, the condensed vapor will flow down into the traps from which it may be removed.

From cooler 12 the compressed air, at atmospheric temperature passes through conduit 22 of section 18, then through conduit 26 of section 19 and conduit 30 of section 20, and through pipe 90 and valve 91, to the intake side of expansion engine 80. In passing through this engine, the air is expanded, and reduced in pressure, and in temperature, and the cooled expanded air passes through pipe 82, trap 83, and pipe 85, to the external conduit 31 of cooler section 20, then by pipe 86 and valve 87 back to the compressor. It will be understood that the compressor will not, under these conditions, be working to a pressure beyond the capacity of the expansion engine. The operation described will result in a regenerative or accumulative cooling of section 20 to a temperature sufficiently low to deposit the greater part of the vaporized oil and aqueous vapor of the compressed air, so that the compressed air may then be admitted to the liquefier without danger of clogging. Owing to the large size of the pipes 30 in section 20, the frozen moisture and oil deposited therein does not interfere with the operation. In order, however, to similarly cool the section 18 in addition to section 20, and thereby further protect the liquefier, the valves 87, 94, 69 and 77 may be closed and valves 93, 95, and 74 open, and the cold exhaust from the expansion engine 80 then flowing, first through section 20 as above explained, and then by pipe 92, valve 93, pipe 71, external conduit 21 and pipe 73 to the intake of the low pressure cylinder of the compressor.

The counter-current sections 20 and 18 having been cooled as above described, so that the compressed air reaches the conduit part 34 at a sufficiently low temperature, valves 35, 94, 93, 95, 74 and 69 are opened and the valves 91, 87 and 77 closed. Valves or cocks 97, 98 and 99 are generally closed. The compressed air now passes through valve 35 to the internal conduit or pipe 37 of the liquefier and from the latter enters the chamber 40 of the expansion valve. The valves 45, 49, having been properly opened, the compressed air expands or discharges by free expansion through the openings 47 into the intermediate chamber 41, and from the latter a part of the air is allowed to expand through valve 49 to the outer chamber or receiver 43. The attendant manipulates the valves so as to maintain the proper relative pressures in the respective chambers. Thus with a pressure of about 3000 to 4000 lbs. per square inch in the inner valve chamber 40, the pressure in the intermediate chamber 41 may be kept at about 60 lbs. gage pressure per square inch and that in the low pressure chamber 43 may be but little above atmospheric pressure. The pressure in pipe 71 leading from the liquefier to valve 94 is maintained slightly higher than in pipe 92 leading from cooler 20.

The air in expanding through valves 45 is cooled by work done internally on the air in well known manner, and the part of the air that expands into the outer chamber 43 is further cooled in the same manner. The air that passes from the intermediate pressure chamber 41 up through conduit 42, is in regenerative or temperature interchanging relation with the incoming air in the inner conduit. From the liquefier, this air, at intermediate pressure, say 60 lbs. to the square inch, passes through pipe 70 to external conduit 27 of section 19, wherein it interchanges temperatures with the compressed air, and therefore leaves said section comparatively warm. From cooler conduit 27 it flows through pipes 76, 79, to the motor or expansion engine 80, where it is expanded to about atmospheric pressure and considerably reduced in temperature, and the cold exhaust from this engine passes by pipe 85 to cool the section 20 as above explained. From conduit 31 of section 20, the cold air passes through the pipes 92 and 71 and section 18 of the return current apparatus and thence to the low pressure compressor cylinder by pipes 73, or it may be allowed to escape from valve 99. In case all of the air supplied at intermediate pressure is not required in the expansion engine 80, valve 77 may be opened to cause any desired proportion of such air to pass directly to the intermediate compression cylinder 4.

The low pressure cold air from chamber 43, which may comprise from one-third to one-fifth of the total quantity of air passing into the liquefier, and is of a lower temperature than the air or liquid in chamber 41, passes directly up and around the intermediate chamber 41 and around the return conduit 42, forming a cold envelop for said conduit for its whole length and passing out through pipe 71 and valve 94, where it mixes with the air coming through pipe 92 from section 20 and together they pass through valve 95 to the first section 18 of the counter-current apparatus. After passing through the external conduit 21 of said section it passes by pipe 73 and valve 74 to the intake of the low pressure cylinder. By the regenerative or self-intensive effect of the continuous or repeated operations of this kind, the compressed air in the liquefier is so cooled that upon its expansion at valves 45, 49, part of it liquefies.

As the intermediate chamber 41 of the liquefier opens directly up into the lower end of the intermediate conduit 42 and said chamber and conduit completely surround the high pressure chamber 40 and conduit 38, respectively, and as the chamber 41 and return conduit 42 are completely inclosed by the outer chamber 43 and return conduit 44, which are at a still lower temperature, and as practically no heat can pass into said chamber 41 and conduit 42 from the outer air, since heat cannot be transmitted either by radiation or conduction from a body at a lower temperature to a body at a higher temperature, the return current of expanded air in conduit 42 exerts a cooling action to substantially its full capacity on all the compressed air coming from the compressor.

It will be noted that the return currents of expanded air pass in the liquefier from the axial or central portion to the inner helix and thence to the outer helix, so that the temperatures of the conduits decrease progressively toward the center, and the inner conduit portions are insulated or protected from external heat.

In utilizing this apparatus for the separation of atmospheric air into commercial oxygen and nitrogen, the condensed product is allowed to accumulate in both of the receivers 41 and 43, until the liquid in receiver 41 partly or wholly surrounds chambers 39 and 40 and the liquid in receiver 43 partly or wholly surrounds receiver 41. It will be understood that the liquid in receiver 41 will be continuously evaporating from the heat carried into chambers 39 and 41 by the compressed air and owing to the lower boiling point of nitrogen, the gas passing off into conduit 42 will be comparatively rich in nitrogen, while the product passing into the outer vessel 43 and conduit 44 will be comparatively rich in oxygen. The contents of the outer vessel will receive heat from the outer air through the casing and insulation by conduction and radiation, and also from the inner receiver 41, the liquid in which being at a higher pressure is also at a higher temperature, consequently commercial oxygen will continuously pass up through the outer conduit 44. The two separated gases from conduits 42 and 44 are delivered through the separate conduits 70, 71, etc., to the respective valves or cocks 97, or 98, and 99, where they may be drawn off as desired, after having abstracted heat practically to their full capacity from the incoming compressed air. When making commercial oxygen and nitrogen in this manner, valves 87 and 93 are closed so as to direct the nitrogen from conduit 31 of section 20, to valve 97, and prevent it from mixing with the oxygen in pipe 71, while valve 74 is closed to cause the oxygen to pass out at valve 99. Suitable connections and storage means will, of course, be provided to receive the commercial oxygen and nitrogen.

What I claim is:—

1. The process of liquefying air which consists in compressing the air, abstracting the heat due to compression, regeneratively cooling the air in several stages, expanding all the compressed air by free expansion to intermediate pressure, passing a part of the air at intermediate pressure in regenerative

relation with the compressed air at one stage of the cooling operation, then adiabatically expanding such air to a low pressure, and passing same by itself in regenerative relation with the compressed air at another stage of the cooling operation expanding the remainder of the air at intermediate pressure to low pressure by free expansion, and passing all the expanded air at low pressure except that which is liquefied, conjointly in regenerative relation with the compressed air at still another stage of the cooling operation.

2. The process of liquefying air which consists in compressing same, abstracting therefrom the heat due to compression, adiabatically expanding said compressed air to a temperature and pressure short of that required for liquefaction and bringing it in heat interchanging relation with subsequently compressed portions of air to cool and condense therefrom all moisture and oil contained therein, and then liquefying said moisture and oil free gas by further cooling and expanding the same.

3. The process of liquefying air which consists in compressing the same, abstracting the heat due to compression, then regeneratively cooling the air in several stages, expanding all of said cooled compressed air by free expansion to intermediate pressure and a portion of the latter to low pressure to liquefy the same, leading the remaining part of the air at intermediate pressure in regenerative relation with the compressed air at one stage of the cooling operation, then adiabatically expanding this intermediate pressure air and leading it in regenerative relation with the compressed air at another stage of the cooling operation.

4. The process of liquefying air which consists in compressing the same, abstracting the heat due to compression, then regeneratively cooling the air in several stages, expanding all the compressed air so cooled to intermediate pressure, leading a part of the air at intermediate pressure in regenerative relation with the compressed air at one stage of the cooling operation, then expanding the remainder of this intermediate pressure air to low pressure and leading the portion unliquefied in regenerative relation with the compressed air at another stage of the cooling operation.

5. The process of separating air into two parts, one rich in oxygen, and the other poor in oxygen, consisting in liquefying the air by successive expansions of compressed air to intermediate and low pressures to form two bodies of liquid at the intermediate and low pressures, maintaining such bodies of liquid and the compressed air just before first expansion in heat-interchanging relation whereby a gas rich in nitrogen evaporates from the body of liquid at intermediate pressure and a gas rich in oxygen evaporates from the liquid at low pressure.

6. The process of fractional separation of liquefied air into nitrogen and oxygen consisting in expanding compressed air successively to different pressures to form bodies of liquid at such pressures, and then distilling off from such bodies of liquid, fractions rich in nitrogen and oxygen respectively, by maintaining said bodies of liquid and air just before first expansion in heat-interchanging relation.

In testimony whereof, I have signed my name to this specification in the presence of two subscribing witnesses, at Los Angeles, in the county of Los Angeles, and State of California, this 9th day of May, 1904.

GABRIEL A. BOBRICK.

In the presence of—
Arthur P. Knight,
Frederick O. Lyon.