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R. P. PICTET.

APPARATUS FOR LIQUEFYING AIR AND OTHER GASES.

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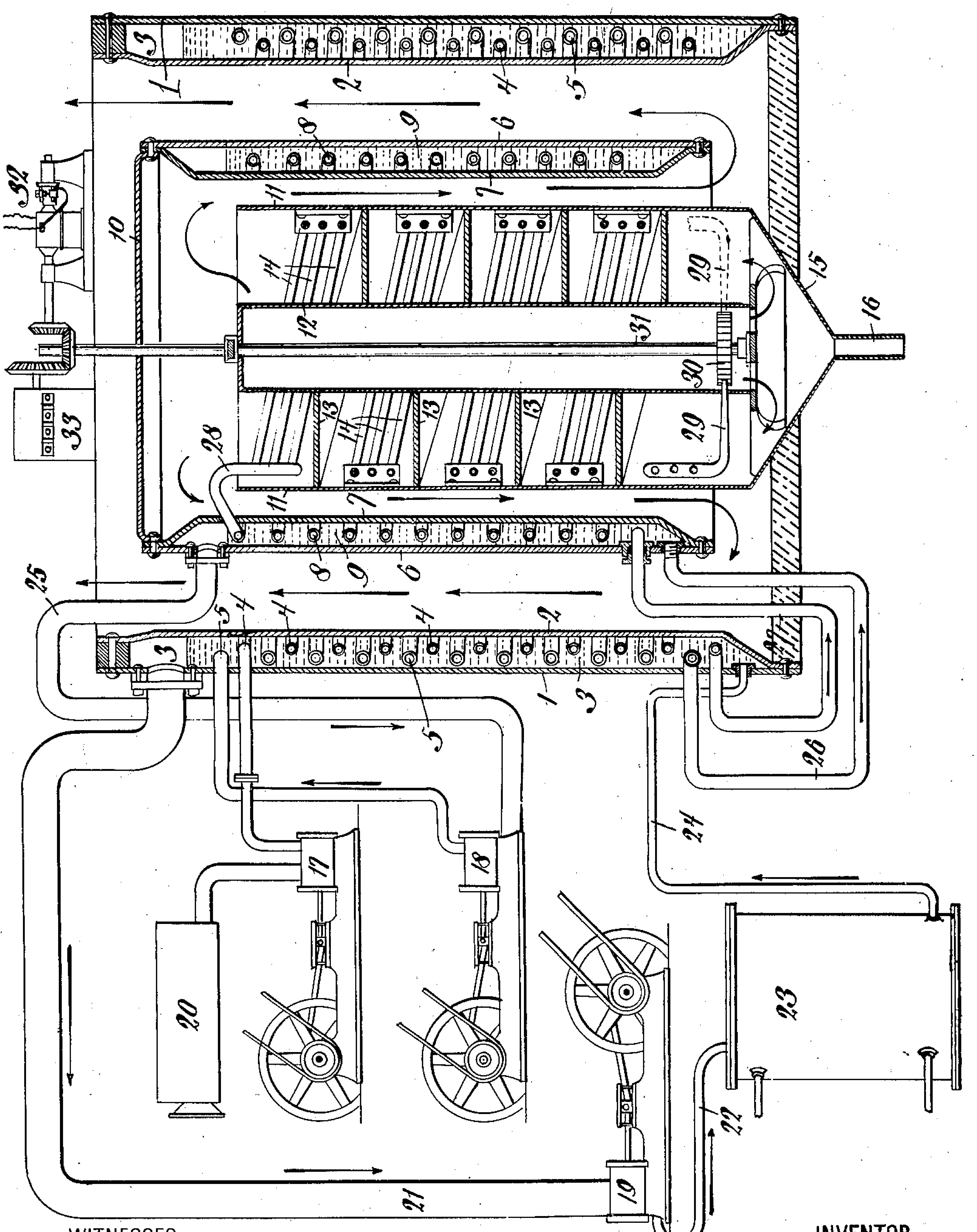

WITNESSES:

D. H. Haywood

Harry S. Marsh

INVENTOR

R. P. Pictet

BY

E. M. Marble & Son

ATTORNEYS

UNITED STATES PATENT OFFICE.

RAOUL PIERRE PICTET, OF NEW YORK, N. Y.

APPARATUS FOR LIQUEFYING AIR AND OTHER GASES.

No. 830,613. Specification of Letters Patent. Patented Sept. 11, 1906.

Application filed January 12, 1901. Serial No. 42,951.

To all whom it may concern:

Be it known that I, RAOUL PIERRE PICTET, a citizen of the Swiss Confederation, residing at New York, in the county of New York and State of New York, have invented a new and useful Apparatus for Liquefying Air and other Gases; and I do hereby declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same.

My invention relates to improvements in apparatus for liquefying air or other gases capable of being liquefied only at low temperatures and usually under pressure.

My invention consists in the novel construction, character, and arrangement of the cooling devices employed for cooling the entering current of air or other gas, in the novel means employed for reducing the pressure of the liquefied gas without the evolution of heat in the apparatus due to such reduction in pressure and with minimum evaporation of the liquid, in the employment of means for converting into useful work the energy contained within the liquefied gas prior to its reduction in pressure, and generally in the novel combination, construction, and arrangement of the parts of the apparatus.

The objects of my invention are, first, to liquefy air and other gases more efficiently and with less expense than has been possible heretofore; second, to prevent so far as possible evaporation of the liquefied gas as an incident to the operation of the apparatus; third, to prevent so far as possible the production of heat in the apparatus; fourth, to convert into useful work so far as possible the energy existing in the liquefied gas after liquefaction and prior to the reduction of the pressure on the liquid, and generally to make the apparatus as simple, economical, efficient, and easily operated as possible. These objects are attained in the apparatus herein described, and illustrated in the drawing which accompanies and forms a part of this application, in which the main portion of the apparatus—viz., the liquefier—is shown in section, the other portions of the apparatus being indicated diagrammatically and not to scale.

The general method of operation of the apparatus herein illustrated and described is as follows: Air or other gas to be liquefied which has first been dried and filtered, if necessary, is compressed. In the case of air the degree of compression need not be greater than fifty-three atmospheres, this pressure corresponding to the critical temperature of liquefaction of air. The air or other gas so compressed is passed through a succession of cooling coils, pipes, or passages, themselves cooled by contact with a rapidly-evaporating liquid refrigerating agent, such as liquid sulfurous acid, liquefied ammonia, chlorid of ethyl, or any other volatile liquid used in refrigerating-machines. I prefer, however, to use the mixture of sulfurous and carbonic acids known as "liquide Pictet." A combined vacuum and compression pump creates a vacuum above the body of evaporating refrigerating agent, so as to hasten the evaporation, and at the same time compresses the gas so drawn off and passes it through a condenser, so as to liquefy it again. From these cooling-coils the compressed and cooled air or other entering gas, which by the treatment just mentioned may have been cooled to $-80°$ or $-100°$ centigrade, is passed through other cooling coils, pipes, or passages themselves subject to the action of a liquid refrigerating agent having a much lower boiling-point than that liquid which cools the primary cooling-coils and which is itself evaporated, compressed, condensed, and returned in the same manner as the primary refrigerating agent. By this second cooling the entering current of air or other gas to be liquefied may usually be cooled to such a temperature that under the pressure to which it has been compressed it will liquefy. For the secondary refrigerating agent I preferably employ ethylene or protoxid of nitrogen, either of which agents permits the cooling of air to from $-140°$ to $-150°$ centigrade. The air thus liquefied is under considerable pressure, and to permit it to be stored economically or to be used for most purposes it must be relieved of this pressure. This may be accomplished most expeditiously by allowing the liquefied air to escape through a suitable orifice and fall into a suitable receptacle; but because of the pressure to which it is subjected the liquid air in so issuing will have great velocity, and if the jet be interrupted or deflected downward by a suitable baffle-plate the energy of the rapidly-moving particles of liquid will be converted into heat, which is objectionable for two reasons—first, because by reason of this evolution of heat a needlessly great proportion of the liquid air will be caused to evaporate, and, second, because the energy so converted into heat is wasted. For this reason I preferably locate in front of the jet a turbine or other suitable fluid-motor operated by the impact upon it of the jet of liquid air. The blades or buckets of this motor are, in effect, yielding spatter-plates; but it is the well-known property of such motors when operating efficiently to absorb the momentum of the fluid by which they are operated, the fluid dropping vertically or nearly vertically downward upon leaving the blades or buckets. By this means the energy of the issuing jet of liquid air is absorbed without the evolution of any considerable amount of heat within the apparatus in so doing, and the energy so imparted to the fluid-motor may be absorbed in operating machinery of any type, and therefore may, if desired, be returned to the system.

Referring now to the drawing, numeral 1 designates the outer casing of the liquefier, which casing is a cylindrical shell. Within it is a second casing 2, connected to casing 1 at top and bottom and inclosing, with casing 1, a jacket 3, adapted to contain a volatile fluid and also containing pipe-coil 4 and 5. The central space surrounded by casing 2 is open at top and bottom. In this space is a second vessel formed by casings 6 and 7, together inclosing a jacket adapted to contain a volatile fluid and containing a pipe-coil 8. The second or inner jacket is numbered 9. This second vessel is open at the bottom, but is closed at the top by a cover-plate 10. Within the said vessel is still a third vessel 11, and within vessel 11 is a tube 12, open at the bottom. Within the space between the walls of vessel 11 and tube 12 is a helical partition 13, dividing this chamber so as to make it a helical passage, and within said helical passage are helical pipe-coils 14. The vessel 11 has a conical bottom 15, to which a pipe 16 for carrying off the liquid air is connected.

Numerals 17, 18, and 19 designate three compressors. Compressor 17 draws atmospheric air or other gas from a filter and dehydrator 20, compresses said air to a pressure of from fifty to fifty-three atmospheres, and delivers the compressed air to the coils 4 within the outer jacket 3. This jacket contains the liquide Pictet, liquid sulfurous acid, liquefied ammonia or chlorid of ethyl or other primary refrigerating agent which may have been selected. Such liquid evaporates rapidly in the jacket 3, the more so because the compressor 19 is arranged to draw off the vapors from the jacket 3 through a pipe 21 and in so doing maintains a considerable vacuum in the jacket. The vapors of the primary refrigerant so drawn off, are compressed by compressor 19 to an extent sufficient to liquefy them when cooled, and they are then passed through pipe 22, condenser 23, wherein they are condensed and cooled, and pipe 24, back to the jacket.

The primary refrigerant in evaporating within the jacket 3 cools the entering air in pipe-coils 4 and also the substance in the coils 5, which is the secondary refrigerant, such as protoxid of nitrogen or ethylene. The main body of this secondary refrigerant is contained in the second jacket 9, and the vapors which are formed in said jacket 9 by the evaporation of the secondary refrigerant are drawn off by the compressor 18 through the pipe 25, are compressed to a pressure of from five to fifteen atmospheres, are cooled by passing through the coils 5, themselves cooled by the primary refrigerant, and are thereby liquefied, and are then returned through pipe 26 to the jacket 9.

The gas to be liquefied after passing through the pipe-coils 4 immersed in the primary refrigerant is led by a pipe 27 to the pipe-coils 8, immersed in the body of the secondary refrigerant contained in the second jacket 9. In its passage through these coils 8 the air or other gas to be liquefied is cooled to such an extent that being under considerable pressure it is liquefied, but although it is now a liquid its pressure must be reduced to that of the atmosphere, and likewise its temperature must be lowered to that of liquid air (or whatever other gas is being treated) at atmospheric pressure. To accomplish this, the liquid air or other substance is conducted by a pipe 28 to the pipe-coils 14 within the helical passages of the vessel 11 and passes downward through said coils 14, which are surrounded by an upwardly-moving current of cold air until the liquid finally passes through a nozzle 29 and impinges upon the buckets of a turbine-wheel 30, mounted upon a revoluble shaft 31, mounted within the tube 12. The liquid as it issues from the nozzle 29 has a high velocity, due to the pressure which impels it; but upon encountering the turbine 30 the velocity of the liquid is imparted to the blades of the turbine, the liquid itself falling downward. A portion of the liquid will evaporate and will pass off through the helical channels of the vessel 11, abstracting heat as it does so from the incoming air in the coils 14 and so cooling such incoming air; but the proportion of liquid which thus evaporates is very much less than would otherwise be the case, owing to the use of the turbine 30, for if the energy of the stream of liquid under pressure were not imparted to the turbine it would be converted into heat through the impinging of the liquid upon the sides of the apparatus or otherwise, and thus a considerable proportion of the liquid would be evaporated. The energy imparted to the turbine is a measure of the energy that otherwise would be converted into heat in that part of the apparatus where it is least desirable that heat should be produced.

The shaft 31 may be caused to drive suitable machinery, and thereby the power imparted to the turbine may be utilized and, if desired, may be returned to the system in this manner. In the drawing the shaft 31 is shown as driving an electric dynamo 32; but of course machinery of any other type may also be driven therefrom. The shaft 31 may also drive a meter 33 by which the amount of liquid air produced may be measured, for after the apparatus is operating in the normal manner the number of revolutions of the sha t 31 in a given time will be a measure of the amount of liquid air produced in that time.

Such of the liquid air as evaporates and passes upward through the helical passages of the vessel 11 passes downward through the annular space between casing 7 and vessel 11 and then upward through the annular space between casings 2 and 6. Such air therefore serves to chill to a considerable extent the entering air. The liquid air which does not evaporate passes out through the pipe 16 and may be collected as produced.

The operation of the apparatus is as follows: The three compressors 17, 18, and 19 being driven from any suitable source compressor 17 draws in air to be liquefied, compresses it to a suitable pressure, which I prefer to be from fifty to fifty-three atmospheres, and delivers it to the coils 4, immersed in the body of primary refrigerant within the jacket 3. The compressor 19 draws the vapors of the primary refrigerant from the jacket 3, in so doing producing a partial vacuum in said jacket, and thereby hastening the evaporation of the primary refrigerant and making it possible to maintain a relatively low temperature in the jacket 3. The compressor 19 compresses such vapors to the necessary extent to insure liquefaction of such vapors upon cooling, and such vapors then pass through the cooler 23, are liquefied therein, and are then returned to the jacket 3. The entering compressed air in passing through the coils 4 is cooled to a temperature of from $-80°$ to $-100°$ centigrade if liquide Pictet is employed as the primary refrigerant. Such air so cooled and still under substantially the initial pressure next passes through the coils 8, immersed in the secondary refrigerant in the jacket 9. Compressor 18 draws the vapors of this secondary refrigerant from the jacket 9, in so doing producing a partial vacuum in said jacket, and thereby hastening the evaporation of the secondary refrigerant and making it possible to maintain a relatively low temperature in the jacket 9. The compressor 18 compresses such vapors to the necessary extent to insure liquefaction of such vapors upon cooling in the pipe-coils 5, immersed in the primary refrigerant within the jacket 3, and such vapors then pass through the coils 5, are condensed and cooled therein, and are then returned in the liquid state to the jacket 9. A pressure of from six to eight atmospheres produced by the compressor 18 will suffice to cause liquefaction of protoxid of nitrogen or ethylene, the secondary refrigerants preferably employed in the coils 5. Cooling of the entering air in the coils 8 suffices to reduce its temperature to from $-140°$ to $-145°$ centigrade. The air so cooled is then passed through the pipe-coils 14 in the helical passages of the vessel 11. Cooling of the air to $-140°$ to $-145°$ centigrade in the coils 8 under a pressure of from fifty to fifty-three atmospheres will suffice to liquefy air; but the air so liquefied is nevertheless cooled to a still lower temperature in its passage through the pipe-coils 14 by radiation of heat to the colder outgoing current of air passing outward around the pipes 14. Finally the air so compressed, cooled, and liquefied emerges from the nozzle or nozzles 29 as a stream of liquid air having a high velocity, owing to the pressure behind it. The energy of such jet or jets is imparted to the turbine 30 and so to the shaft 31 and the machinery driven thereby, the liquid falling from the buckets of the turbine. A portion of this liquid will vaporize, because the temperature of the liquid air issuing from the nozzles is not yet that of liquid air at atmospheric pressure; but the evaporation of this portion of the liquid air will cool the remainder of the liquid to the temperature of liquid air at atmospheric pressure, and such liquid will be collected by the conical bottom 15 and will descend through the pipe 16 and may be caught.

The jacket 3 serves both as an initial cooler for the compressor 17 and as a condenser for the secondary refrigerant. It is therefore unnecessary to employ a separate initial cooler for the compressor 17 and a separate condenser for the secondary refrigerant.

The air which passes up through the helical passages of the vessel 11 passes downward through the annular space between vessel 11 and casing 7 and then upward through the annular space between casings 2 and 6. In so passing it helps to cool the primary and secondary refrigerants and also to insulate the passages 6 and 14 against absorption of heat from the outside.

I do not limit myself to conducting the refrigeration of the entering air in any particular number of stages or to the use of any particular refrigerants. Nor do I limit myself to the treatment of air for liquefying it by the method herein described. I may treat any other gas capable of being liquefied by the application of cold or of cold and pressure in the same way.

I do not limit myself to the use of the particular construction and arrangement of parts herein illustrated.

Preferably two or more nozzles 27 should be employed, and these nozzles should be so spaced around the periphery of the turbine that side thrust is avoided. In the drawing two such nozzles are shown, one being indicated by dotted lines.

The jackets or vessels 3 and 9 may be termed "primary" and "secondary" cooling vessels, respectively.

Having thus completely described my invention, what I claim, and desire to secure by Letters Patent, is—

1. In an apparatus for liquefying air and other gases the combination with a series of cooling vessels adapted to contain liquid refrigerants of successively lower boiling-points, each provided with cooling-passages, for conveying the gas to be liquefied through said cooling vessels, such passages of the said vessels being connected in series, and the vessel for containing the refrigerant of higher boiling-point having other cooling-passages connected with the vessel for containing refrigerant of lower boiling-point, and forming cooling-passages for the refrigerant of lower boiling-point, of means for compressing the vapor of the refrigerant of lower boiling-point, and for passing it through the corresponding cooling-passages of the vessel containing the refrigerant of higher boiling-point, back to its corresponding vessel, and means for compressing the vapor of the refrigerant of higher boiling-point, cooling it and returning it to its corresponding vessel.

2. In an apparatus for liquefying air and other gases, the combination, with primary and secondary cooling vessels, adapted to contain, respectively, primary and secondary liquid refrigerants of progressively lower boiling-points, said cooling vessels each provided with cooling-passages for the gas to be liquefied, said passages of the said vessels being connected in series, the primary cooling vessel being also provided with other cooling-passages connected with the secondary vessel and forming cooling-passages for the secondary refrigerant, of means for compressing the vapor of the secondary refrigerant, and for passing it through the cooling-passages of the primary vessel back to the secondary vessel, and means for compressing the vapor of the primary refrigerant, cooling it, and returning it to the primary vessel.

3. In an apparatus for liquefying air and other gases the combination with a series of cooling vessels adapted to contain liquid refrigerants of successively lower boiling-points, located one within the other, and each provided with cooling-passages, for conveying the gas to be liquefied through said cooling vessels, such passages of the said vessels being connected in series, and the vessel for containing the refrigerant of higher boiling-point having other cooling-passages connected with the vessel for containing refrigerant of lower boiling-point, and forming cooling-passages for the refrigerant of lower boiling-point, of means for compressing the vapor of the refrigerant of lower boiling-point, and for passing it, through the corresponding cooling-passages of the vessel containing the refrigerant of higher boiling-point, back to its corresponding vessel, and means for compressing the vapor of the refrigerant of higher boiling-point, cooling it, and returning it to its corresponding vessel.

4. In an apparatus for liquefying air and other gases, the combination, with primary and secondary cooling vessels, located one within the other, and adapted to contain, respectively, primary and secondary liquid refrigerants of progressively lower boiling-points, said cooling vessels each provided with cooling-passages for the gas to be liquefied, said passages of the said vessels being connected in series, the primary cooling vessel being also provided with other cooling-passages connected with the secondary vessel and forming cooling-passages for the secondary refrigerant, of means for compressing the vapor of the secondary refrigerant and for passing it through the cooling-passages of the primary vessel back to the secondary vessel, and means for compressing the vapor of the primary refrigerant, cooling it, and returning it to the primary vessel.

5. In an apparatus for liquefying air and other gases the combination with a series of cooling vessels adapted to contain liquid refrigerants of successively lower boiling-points, located one within the other, and each provided with cooling-passages, for conveying gas to be liquefied through said cooling vessels, such passages of the said vessels being connected in series, and the vessel for containing the refrigerant of higher boiling-point having other cooling-passages for the refrigerant of lower boiling-point, of means for inducing circulation in the several cooling-passages, means for condensing and returning to the vessel for containing the refrigerant of higher boiling-point, the refrigerant which evaporates therein, and a heat-exchanger within the innermost of said vessels, provided with adjacent passages for entering and outgoing gas, and with an expansion-orifice connecting the same.

6. In an apparatus for liquefying air and other gases, the combination with primary and secondary cooling vessels, the latter located within the former, said vessels containing respectively primary and secondary refrigerants, the latter of lower boiling-point than the former, said vessels provided with cooling-passages, connected in series, for the gas to be liquefied, the primary vessel being also provided with other cooling-passages connected with the secondary vessel and forming cooling-passages for the secondary refrigerant, of means for compressing the vapor of the secondary refrigerant and for passing it through the corresponding passages of the primary vessel back to the secondary vessel, and means for compressing the vapor of

the primary refrigerant, cooling it, and returning it to the primary vessel.

7. In an apparatus for liquefying air and other gases, the combination with primary and secondary cooling vessels, the latter located within the former, and a heat-exchanger within the secondary vessel, spaces for the circulation of gas being provided between the primary and secondary vessels and between the secondary vessel and the exchanger, said vessels containing respectively primary and secondary refrigerants, the latter of lower boiling-point than the former, said vessels provided with cooling-passages, connected in series, for the gas to be liquefied, the primary vessel being also provided with other cooling-passages connected with the secondary vessel and forming cooling-passages for the secondary refrigerant, of means for compressing the vapor of the secondary refrigerant, and for passing it through the corresponding passages of the primary vessel back to the secondary vessel, and means for compressing the vapor of the secondary refrigerant, cooling it, and returning it to the primary vessel, the heat-exchanger being arranged to cause unliquefied gas to pass back through the spaces between the exchanger and the primary and secondary vessels.

8. In an apparatus for liquefying air and other gases, the combination, with primary and secondary cooling vessels, located one within the other, and adapted to contain, respectively, primary and secondary liquid refrigerants of progressively lower boiling-points, said cooling vessels each provided with cooling-passages for the gas to be liquefied, said passages of the said vessels being connected in series, the primary cooling vessel being also provided with other cooling-passages connected with the secondary vessel and forming cooling-passages for the secondary refrigerant, of means for inducing circulation through the several cooling-passages, means for condensing and returning to the primary vessel the refrigerant which evaporates therein, and a heat-exchanger within the innermost of said vessels, provided with adjacent passages for entering and outgoing gas, and with an expansion-orifice connecting the same.

9. In an apparatus for liquefying air and other gases, the combination with a series of cooling vessels adapted to contain liquid refrigerants of successively lower boiling-points, each provided with cooling-passages, for conveying gas to be liquefied through said cooling vessels, such passages of the said vessels being connected in series, and the vessel for containing the refrigerant of higher boiling-point having other cooling-passages for the refrigerant of lower boiling-point, of means for inducing circulation in the several cooling-passages, means for condensing and returning to the vessel for containing the refrigerant of higher boiling-point, the refrigerant which evaporates therein, and a heat-exchanger within the innermost of said vessels, provided with adjacent passages for entering and outgoing gas, and with an expansion-orifice connecting the same, there being a passage between the exchanger and the adjacent cooling vessel, in communication with the outgoing passage of said exchanger, through which the outgoing gas may flow.

10. In an apparatus for liquefying air and other gases, the combination, with primary and secondary cooling vessels, located one within the other, and adapted to contain, respectively, primary and secondary liquid refrigerants of progressively lower boiling-points, said cooling vessels each provided with cooling-passages for the gas to be liquefied, said passages of the said vessels being connected in series, the primary cooling vessel being provided also with other cooling-passages connected with the secondary vessel and forming cooling-passages for the secondary refrigerant, of means for inducing circulation through the several cooling-passages, means for condensing and returning to the primary vessel the refrigerant which evaporates therein, and a heat-exchanger within the innermost of said vessels, provided with adjacent passages for entering and outgoing gas, and with an expansion-orifice connecting the same, there being a passage between the exchanger and the adjacent cooling vessel, in communication with the outgoing passage of said exchanger, through which the outgoing gas may flow.

11. In an apparatus for liquefying air and other gases the combination with a series of cooling vessels, located one within the other, and adapted to contain liquid refrigerants of successively lower boiling-points, each vessel provided with cooling-passages, for conveying gas to be liquefied through said cooling vessels, such passages of the said vessels being connected in series, and the vessel for containing the refrigerant of higher boiling-point having other cooling-passages for the refrigerant of lower boiling-point, of means for compressing the vapor of the refrigerant of lower boiling-point, and for passing it, through the corresponding cooling-passages of the vessel containing the refrigerant of higher boiling-point, back to its corresponding vessel, means for compressing the vapor of the refrigerant of higher boiling-point, cooling it, and returning it to its corresponding vessel, and a heat-exchanger within the last of said vessels, provided with adjacent passages for entering and outgoing gas, and with an expansion-orifice connecting the same, and a motor within the heat-exchanger arranged to be actuated by fluid issuing from said orifice.

12. In an apparatus for liquefying air and other gases the combination with a series of

cooling vessels, located one within the other, and adapted to contain liquid refrigerants of successively lower boiling-points, each vessel provided with cooling-passages, for conveying gas to be liquefied from said cooling vessels, such passages of the said vessels being connected in series, and the vessel for containing the refrigerant of higher boiling-point having other cooling-passages for the refrigerant of lower boiling-point, of means for compressing the vapor of the refrigerant of lower boiling-point, and for passing it, through the corresponding cooling-passages of the vessel containing the refrigerant of higher boiling-point, back to its corresponding vessel, means for compressing the vapor of the refrigerant of higher boiling-point, cooling it, and returning it to its corresponding vessel, a heat-exchanger within the last of said vessels, provided with adjacent passages for entering and outgoing gas, and with an expansion-orifice connecting the same, and a turbine-motor within the heat-exchanger arranged to be actuated by fluid issuing from said orifice.

In testimony whereof I affix my signature in the presence of two witnesses.

RAOUL PIERRE PICTET.

Witnesses:

ERNEST H. DE VINE,

D. HOWARD HAYWOOD.