F. E. NORTON.

PROCESS OF REFRIGERATION.

APPLICATION FILED JAN. 29, 1916.

1,292,958.

Patented Jan. 28, 1919.

3 SHEETS—SHEET 1.

Fig. 1.

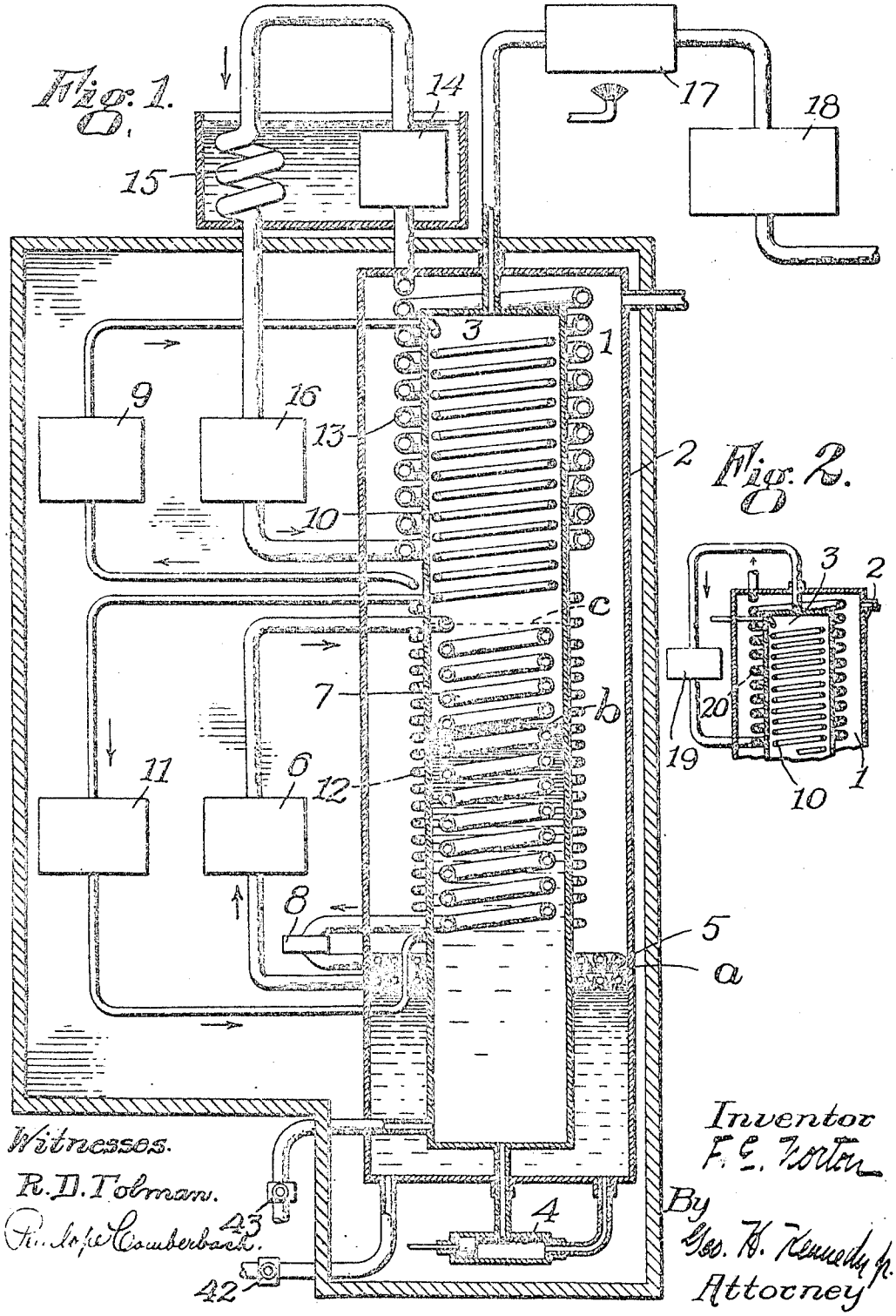


Fig. 2.

Witnesses.

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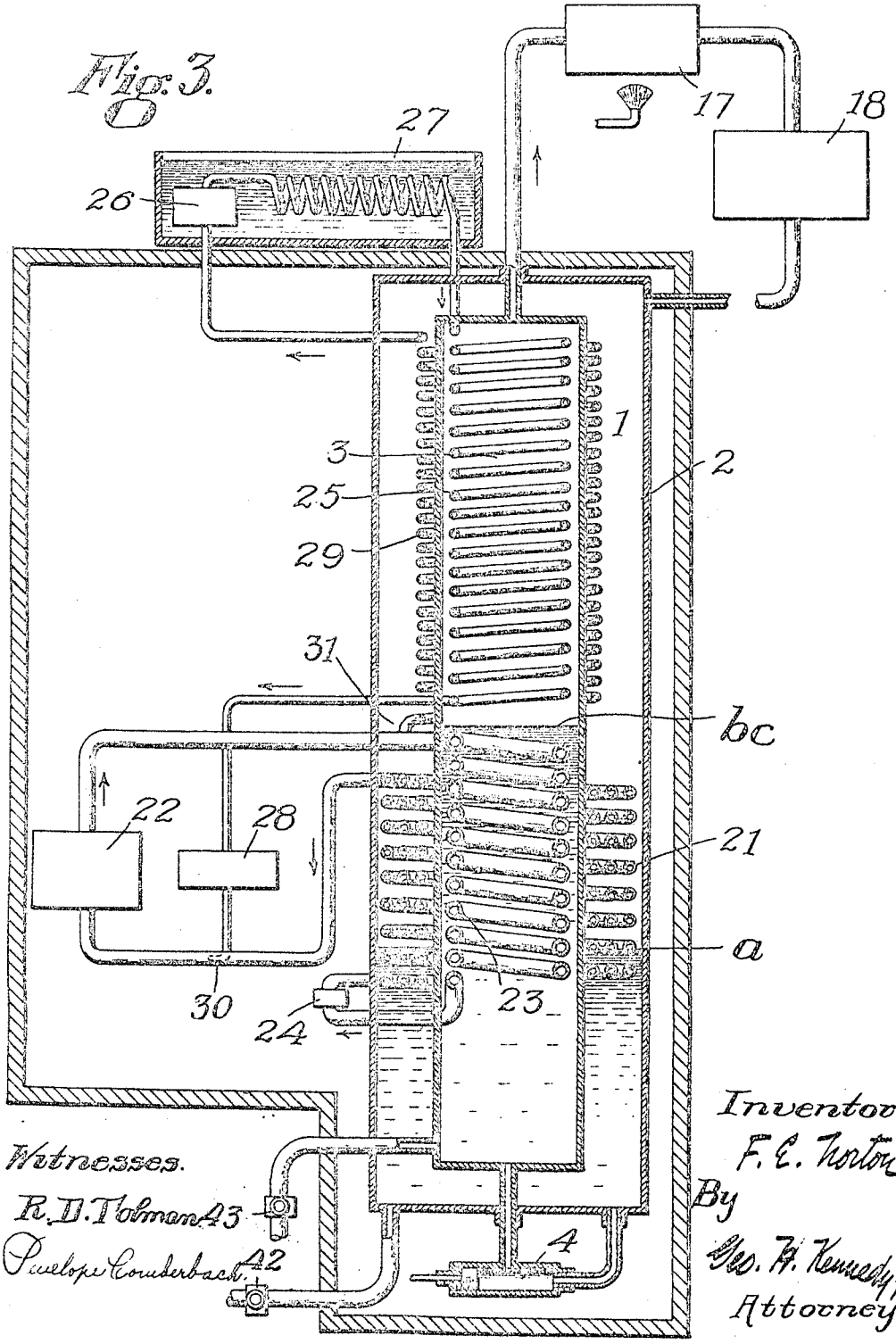
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3 SHEETS—SHEET 2.

Fig. 3.



Witnesses.

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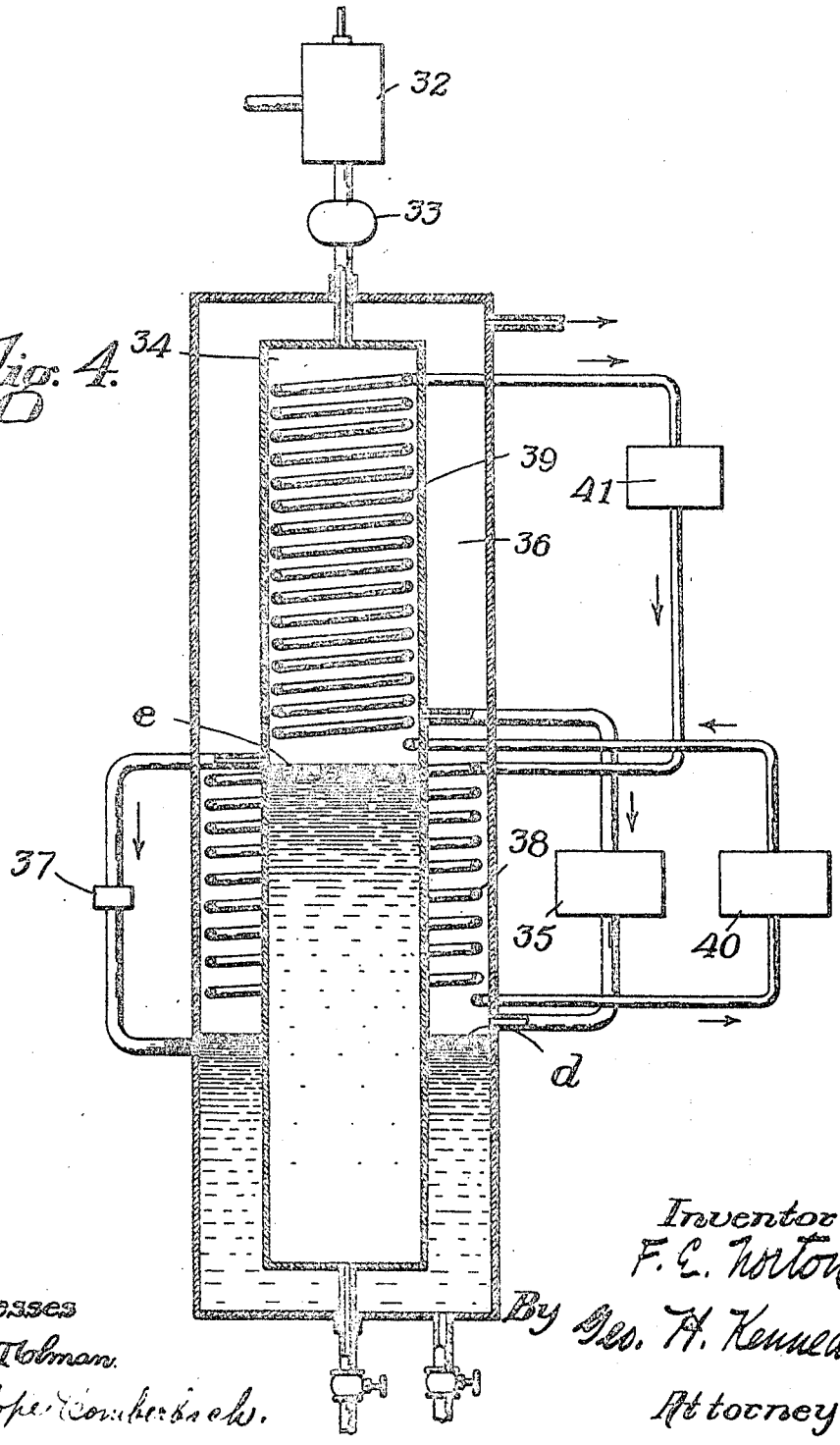
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3 SHEETS—SHEET 3.

Fig. 4.



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PROCESS OF REFRIGERATION.

1,292,958. Specification of Letters Patent. Patented Jan. 28, 1919.

Application filed January 29, 1916. Serial No. 75,009.

To all whom it may concern:

Be it known that I, FRED E. NORTON, a citizen of the United States, residing at Worcester, in the county of Worcester and Commonwealth of Massachusetts, have invented a new and useful Improvement in Processes of Refrigeration, of which the following, together with the accompanying drawings, is a specification.

The present invention relates in general to processes of refrigeration, and has particular reference to improvements in processes of this class which, in general, contemplate the attainment of extremely low temperatures by the use of a gaseous working fluid. The low temperatures attained in the present process, in common with the processes previously practised, may be used, if desired, in securing extreme refrigerative effects; or the process may be carried on for the purpose of liquefying, in whole or in part, the gas, and if desired, this liquefaction, if the gas be a mixed gas, may be employed in connection with suitable distillation agencies to effect the separation of the gas into its constituent elements. Moreover, as will be shown, the process may with advantage be utilized for the cheap and efficient production of power, in a form available for the production of useful work.

The process of the present invention contemplates the attainment of marked improvements in efficiency and capacity over the processes of this class heretofore known; the principles of the invention and the various steps employed in the application of said principles to the accomplishment of the desired results are fully set forth in the following description and pointed out in the annexed claims, reference being had to the accompanying drawings which illustrate, diagrammatically, three different arrangements of apparatus by means of which the novel steps of my process may be put into practice.

Referring to the said drawings, wherein like reference characters are used to indicate like parts in the several views,

Figure 1 is a diagrammatic representation of one arrangement of apparatus which may be employed, and which is most susceptible to the explanation of the novel and useful steps which constitute my invention.

Fig. 2 is a fragmentary illustration of a modification of the apparatus shown in Fig. 1, introduced herein for explanatory purposes.

Fig. 3 is a diagrammatic representation of an arrangement of apparatus illustrative of what I now contemplate as being a preferable arrangement for the application of the aforesaid novel and useful steps.

Fig. 4 is a diagrammatic representation of an arrangement of apparatus illustrating the application of certain of the novel steps of my invention to a system which may be said to be typical, in a general way, of the refrigeration and liquefaction systems of the prior art.

It is to be understood, however, that the carrying out of my invention is not in any way confined to the employment of the herein described or any other particular arrangement of apparatus, nor to the herein described methods of utilizing such apparatus, except in so far as specified in the appended claims; the drawings and description being illustrative merely, and disclosing only a few specific applications which I now regard as being advantageous for the accomplishment of the novel steps hereinafter set forth.

As heretofore practised, processes of this class, which may or may not involve the complete liquefaction of the working fluid, depending upon the ultimate purpose to which the refrigeration is to be applied, have shown extremely low efficiency and capacity for refrigeration, by reason of the demands made upon the external cooling agency in attaining the desired low temperatures, such systems, therefore, requiring large expenditures of power for supplying the necessary refrigerative effect. In such processes, especially where liquefaction for the ultimate purpose of separation is contemplated, preliminary compression of the gas to be separated, and sometimes even higher compression of the gas used in the external cooling agency, has invariably been employed, in order that condensation may occur at a fairly high temperature. Since an expansion device returns useful work in less and less degree as the temperature of the fluid to be expanded is lowered, this preliminary compression of the gas has, in the past, been resorted to in order that the expansion devices of such systems may work at as high a temperature as possible. In such previous processes, however, this small

apparent gain in the efficiency of the external cooling agency has been more than offset by the cost of highly compressing the working fluid, since substantially all the work of this compression is dissipated in the system owing to the fact that the release from pressure of a large portion of the working fluid is relied upon to effect its liquefaction, and this occurs without any production of external work. That is to say, in all such prior processes the gas issuing from the system in countercurrent to the incoming compressed gas, irrespective of whether it has passed through the liquid state, or whether, if a mixed gas, its components issue in separated form, is invariably under such a low pressure that the recovery of any power therefrom is out of the question.

According to the present process, the step of preliminary compression may be wholly omitted or at least the degree of compression may be substantially reduced; the gas may be taken in under substantially atmospheric conditions, and may be caused to leave the system under a much higher pressure, in such a condition as to be available for furnishing a considerable portion of the power required to produce the desired refrigeration and liquefaction of the working fluid. In this connection, the adaptation of the principles underlying my process to the efficient and cheap production of power in addition to the specific utility of said principles for the liquefaction and separation of gases, such as air, will be readily understood, it being clear, from what follows, that the working fluid employed in the process is brought to a high pressure by the minimum expenditure of work, and in this condition is available as a motive fluid, with or without the addition of external heat.

While it is clear that the mechanical imperfections of any given apparatus invariably preclude the attainment of a perfect efficiency, and while it is also apparent that a process of the character herein set forth is always limited by such mechanical imperfections, still it is unquestioned that the final efficiency of such a process will attain the highest degree only when the several actions occurring therein are reversible in character, at least in theory. It has been shown that in prior processes of this class, the actions are irreversible. That is to say, the flow of heat from a higher to a lower temperature, or level, without effecting external work, as by the release of pressure above described, is a characteristic action of prior processes of this class, and as such, is an irreversible action, *i. e.*, an action requiring an expenditure of work to restore the substance to its original condition. According to the present process, the several heat exchanging actions between different portions of the fluids in different stages of the process will be shown to be substantially reversible, at least in theory, in contra-distinction to the wholly irreversible actions which are characteristic of prior processes of this class; as a consequence, in theory at least, the work required in order to effect the desired refrigeration is simply that work which is necessary in order to overcome the mechanical imperfections of the apparatus, it being assumed, for the present purposes, that the inleakage of external heat is properly guarded against by the provision of suitable insulation.

With reference to the application of the principles above set forth to the attainment of the objects and advantages hereinbefore mentioned, the diagrammatic illustration of Fig. 1, together with the several steps of the process which are carried out by the apparatus therein illustrated, will now be set forth in detail.

Referring to Fig. 1, the gaseous working fluid used in the process is led, under atmospheric pressure, or under only a nominal pressure, into a passage 1 of a heat interchanger, designated as a whole by the numeral 2. This interchanger, which is herein represented in purely conventional form, has a countercurrent passage 3, in intimate thermal relation to the passage 1. I have selected, for purposes of illustration, a form of apparatus in some respects resembling that shown in my copending application Serial No. 11,850, filed March 3, 1915; in common with the invention disclosed in said copending application, the working fluid, after liquefaction under low pressure in the passage 1, in the manner hereinafter set forth, is transferred to the passage 3 by a pump or other pressure increasing device 4, which maintains it in said passage 3 under a pressure considerably in excess of the pressure prevailing in passage 1. The pressure prevailing in the passage 3 is obviously due to the resistance imposed against the outflow of vapor from the upper end of said passage; in forcing liquid in the bottom of passage 3, the pump 4 must put it under sufficient pressure to overcome the pressure prevailing in said passage, which, as above stated, is higher than the pressure prevailing in passage 1.

In common with the invention set forth and described in said copending application, the high pressure liquid in passage 3 is to be evaporated at such increased pressure and returned in countercurrent through the interchanger for the purpose of extracting heat from the incoming gas in passage 1. The heat exchange between the fluids in passages 1 and 3, in a manner similar to that well-known in apparatus of this character, entails the discharge of high pressure fluid from the top or warm end of passage

3 at substantially the temperature of the gas entering the interchanger at the top or warm end of passage 1; the substantial equalization of temperatures at any given level by heat interchange between the two passages 1 and 3, is contemplated, and in common with other apparatus of this character, the temperatures are lower, the lower the level reached in said interchanger. To effect this evaporation in the passage 3, an expedient, somewhat similar to that employed in the process of said copending application, but differing therefrom in certain particulars affecting the ultimate results obtained thereby, is adopted, the same being herein illustrated as a means for transferring the latent heat of condensation from the vapor being condensed just above the surface *a* to evaporate the warmer liquid at the surface *b*. To this end, a coil 5 may be immersed in the liquid formed within the passage 1 of the interchanger and a compressor 6 may be interposed between this cold coil 5 and the warm end of a coil 7 partly immersed in the liquid contained in the passage 3. Said coil 7 communicates at its cold end with an expander or nozzle 8, and the latter is connected to the inlet side of the coil 5, thereby forming a closed circuit. Said circuit may be supplied with a circulating fluid having a boiling point at the same, or a lower, temperature than the fluid to be condensed at the surface *a*. Assuming that the compressor 6 works at a slightly higher pressure than the pump 4, and that the fluid used in said circuit is the same as the working fluid, it will be clear that the circulation by compressor 6, during a given period, of a weight of fluid equal to or slightly in excess of the weight of working fluid entering passage 1 during the same period, will effect this transfer of heat contents, as follows:—

This circulating fluid passing to the coil 5, after its pressure is released in expander 8, may, under the conditions assumed above, be mostly liquid, and while condensing the fluid above the surface *a* by extracting the latent heat of condensation therefrom, it will be substantially evaporated. The vapor, or the mixture of liquid and vapor from the coil 5, passing to the compressor 6, has its pressure and temperature raised by said compressor. Passing in substantially gaseous form to the coil 7, it effects the evaporation of liquid at the surface *b*, by transfer of its heat to said liquid, and is itself condensed thereby in whole or in part. The subsequent release of pressure from said circulating fluid in the nozzle 8 causes its return to the coil 5 in condition to repeat the condensation at the surface *a* in the manner above described.

The actions, above described, will be carried out, under the conditions assumed, very readily, merely by causing the liquid in coil 5 to be slightly colder than the low pressure working vapor to be liquefied at this point, in order to promote the transfer of heat contents in the proper direction, and it will be seen that the difference in temperature relied upon to effect this transfer of heat units between the fluids can be made as small as desired simply by increasing the contact surfaces of the coil. The same is obviously true of the action occurring in the high pressure passage 3, in which a slightly greater pressure or temperature within the coil 7 insures the necessary exchange of latent heats. It will be clear that other conditions affecting the pressure, temperature, composition, and quantity of the circulatory transfer fluid may be adopted, within a wide range, without departing from the principles of the actions above set forth, since the foregoing assumptions were made merely for purposes of explanation. As has been shown, the transfer of the relatively large quantities of heat between the working and the circulating fluids occurs in each case with only a very slight temperature difference; thus each action as described above, of itself, therefore, approaches reversibility as closely as the mechanical imperfections inherent in the apparatus will permit. That is to say, the absorption and rejection of latent heat by the working and circulating fluids, as described above, takes place under substantially constant temperature and hence with the highest possible efficiency. Obviously, the circulating fluid which is alternately compressed and expanded in the compressor 6 and nozzle 8 need not be confined to the coils 5 and 7, as above described, but may be constituted by fluid taken directly from and returned to the supply of working fluid present in the passage 3 of the interchanger, as fully set forth in my aforesaid copending application, in which case the quantity of fluid circulated in the heat transfer system would be in a predetermined proportion to the quantity of working fluid handled by pump 4. The above described use of the circulating coil 7 is adopted simply for the sake of clearness and to avoid confusion in the explanation of my process.

As fully set forth in my said copending application, the high pressure gas thus evaporated at the surface *b* has, by reason of its increased specific heat, a greatly increased heat absorbing capacity; in other words, it is capable of removing from the system a greater amount of heat per degree of temperature than is brought in by the same weight of fluid entering the passage 1. In the present process, a portion of this available excess cooling effect may be utilized in removing from the transfer fluid any superheat, as would result from the in-

troduction to the compressor 6 of said fluid in the form of a saturated vapor. As herein shown, the coil 7 extends above the liquid level *b* in the passage 3, it being assumed, for purposes of illustration, that superheating of the transfer fluid, to a degree indicated by the temperature level *c* of the interchanger, has occurred. The liquid, therefore, does not rise to level *c*, but boils off so as to remain at a level somewhat below *c*, the exact position of which, *b*, is obviously dependent wholly on the amount of superheat. Between the levels *b* and *c* the high pressure evaporate with its relatively high heat absorbing capacity, accomplishes the removal of this superheat.

As pointed out in said copending application, there is a deficiency in the cooling effect available for condensing the incoming low pressure gas near the lower end of passage 1, notwithstanding the fact that in the process of said copending application the temperature of said gas is lowered, by heat exchange with the high pressure liquid; this deficiency is due to the fact that the substance under low pressure has greater latent heat than the same substance under high pressure. In the process of said copending application an expansion engine, or other equivalent cooling agency, was required to supply this deficiency in cooling effect and, as shown, it had to perform its work of cooling at the extremely low temperature necessary to effect condensation in the low pressure passage of the system.

In the present process, not only is the necessity for an external cooling agency working at such a low temperature wholly avoided, but, if desired, the high pressure liquid in passage 3 may impart all of its cooling effect to the transfer fluid in coil 7, since such cooling effect is not essential to the cooling of the low pressure vapor in passage 1. According to the present invention the excess of cooling effect present in the high pressure gas above the level *c* is employed to supply the deficiency of cooling effect in the cold end of the low pressure passage 1, and to this end the arrangement of apparatus hereinafter described may be employed, although it will be apparent that my invention is not limited in any way to the use of such an arrangement, the particular illustration herein employed being adopted merely for the sake of clearness in explanation.

A compressor 9 is connected with a coil 10 located in the warm end of passage 3. The coil 10 communicates with an expansion engine 11, which in turn is connected to a second coil 12 disposed in the cold end of low pressure passage 1. Said coil 12 is connected to the inlet side of compressor 9, thereby forming a closed circuit. Said circuit is supplied with a circulating fluid which may be the same as the working fluid, and as in the case of the circulating fluid in the system 5, 6, 7 and 8, it may, for illustrative purposes be assumed that the weight of fluid circulated by the compressor 9, during any given period, is the same as, or slightly in excess of, the weight of the working fluid entering passage 1 in the same period, the compressor 9 working, as before, between substantially the same pressures as the pump 4.

The action under the conditions assumed is approximately as follows:—The fluid in coil 10, at substantially the same pressure as the vapor in passage 3, is progressively cooled, by heat interchange therewith, to the temperature prevailing at level *c;* thereafter, said circulating fluid is expanded to atmospheric pressure through expander 11, being cooled thereby to a temperature approximately that at the level *a*. Returning through the coil 12, in countercurrent to the incoming gas in passage 1, it progressively cools said gas to the temperature of low pressure liquefaction, namely that at level *a* and is itself warmed up to the temperature *c*. From this point it passes to the compressor 9, and after its original pressure and temperature have been restored, it is again passed through the cycle above described. Thus the cooling effect of the escaping high pressure vapor is applied to the incoming low pressure vapor to cool the latter from *c* to *a;* it will be clear that, approximately, the same conditions prevail with respect to this transfer of heat contents as prevail with respect to the transfer of latent heats by the system 5, 6, 7 and 8, above described, namely that at any given point, assuming only a slight difference in temperature in favor of the direction in which it is desired that the exchange should take place, the actions above described occur under substantially constant temperature, and hence, approach reversibility as closely as the mechanical imperfections of the apparatus will permit. Moreover, in the present instance, it will be clear that owing to the greater cooling effect available in the high pressure vapor of passage 3, it is highly desirable to apply this cooling effect at the point where it is most needed, and the fact that this point is at the cold, rather than at the warm end of the interchanger, does not in any way prevent or retard the transfer of heat contents in the manner above described, even though it does necessitate a flow of heat from a lower to a higher temperature. As in the previously described circulatory latent heat transfer system, a wide range is permissible for variation of the pressure, temperature, composition and quantity of the transfer fluid from the conditions assumed above, which were merely for purposes of explanation. Obviously, also, the use of the coils 10 and

12 is not at all essential, the same being shown and referred to merely by way of making the various actions plainer.

In the application of the novel principles above set forth to the actual working conditions existing in refrigeration systems of this class, it will be obvious that as many circulating systems corresponding to the system 9, 10, 11 and 12 may be used as is necessary to effect the drop in temperature from the warm end of the interchanger to the cold end where liquefaction under low pressure takes place. For the sake of clearness in illustration, the present process has been confined to the showing of a single circulating system of this character for the purpose of applying the cooling effect of the high pressure vapor to the low pressure vapor at a lower temperature, but it is clear that for practical working conditions where the working fluid is brought in under substantially atmospheric pressure and is liquefied, the application of this high pressure cooling effect will be best served by the provision of a plurality of circulating systems corresponding to the system 9, 10, 11 and 12, each adapted to work within a range of temperatures of less extent than the total temperature drop required.

The establishment of the conditions illustrated in Fig. 1 may be assumed; or it may be shown that such conditions may be established and that after their establishment the system will operate continuously, in the manner hereinafter described, to take the working fluid, brought in at atmospheric pressure, through the liquid state as shown. In order to start the operation, the compressor 9 and expander 11 may be operated by any source of available power and the heat of compression above atmospheric temperature during this starting may be radiated or absorbed in any suitable manner. Under these conditions, provided the compressor 6 is inoperative, or operates only without pressure, by the opening of nozzle 8, the system will progressively become colder until the gas begins to be liquefied at *a*, whereupon the normal working conditions may be established. It has been shown that the cooling effect of the outgoing substance can be applied to the refrigeration of the incoming substance in a highly efficient manner, and that the resulting condensation of the low pressure vapor can be applied to effect the evaporation of the high pressure liquid. Consequently, the necessity for external refrigerating agencies is confined only to the overcoming of the mechanical imperfections of the apparatus, and to the cooling of the incoming vapor in passage 1 between substantially atmospheric temperature and the temperature prevailing at the level *c* in the interchanger. This cooling effect may be readily supplied at relatively low expense by any well known type of external cooling agency, such as a coil 13, expander 16, water cooler 15, and compressor 14, which latter, for example, may work between the same pressures as the other compressors 6 and 9, and may circulate, in a given time, a weight of working fluid corresponding to the weight entering the low pressure passage 1 during the same time. In this way the external cooling agency, which represents, as will be shown, the bulk of the external power required to operate the system, need only attain a very limited degree of coldness, which constitutes only a small portion of the total temperature drop required. That the external cooling agency above described constitutes, in theory at least, the only external work required to operate the system, is shown as follows:— Under the conditions assumed, the compressor 6 handling the same quantity of fluid and working between the same temperatures and pressures as the expander 11, requires, in theory, the same amount of external work as is delivered by said expander. The above also holds true for the compressor 9 and the expander 16; that is the work required by the former is balanced by the work delivered by the latter. Also, the expansion through nozzle 8, even though at an extremely low temperature, is sufficient, in theory at least, to supply the small amount of work required to operate pump 4, it being clear that these two devices have also been assumed to handle substantially equal quantities of fluid, between substantially the same pressures and at the same temperatures. Therefore, outside of the power required to overcome the losses due to the mechanical imperfections of the several pumps, compressors and expanders above referred to, there remains only the work required to operate the compressor 14, in order to make the process continuous. The high pressure vapor leaving the passage 3 may be heated by any external source of heat 17, and then used in a highly efficient manner in an expansion motor 18 to develop all, or at least a considerable portion of the power required to operate the compressor 14. Obviously, the degree to which this high pressure vapor is heated, *i. e.*, has energy imparted to it, is a measure of the work which it is possible to develop in the motor 18, in excess of the amount available due to its pressure at atmospheric temperature.

While I have shown a high pressure vapor from the passage 3 as being used to develop a portion of the power required to operate the process, by expansion in the motor 18, it will be clear that this vapor, if desired, may be applied to the refrigeration of the incoming low pressure vapor between atmospheric temperature and the temperature of the level *c* by allowing it to expand in a

suitable expansion engine 19, Fig. 2, and by returning said expanded and cooled fluid through a coil 20 or other heat exchanging agency disposed in the warm end of passage 1. The foregoing has been pointed out simply for the purpose of showing that in theory the heat removed from the incoming vapor on the low pressure side of the countercurrent apparatus substantially balances the heat absorbed by outgoing vapor in the high pressure side of the countercurrent apparatus. In other words, excluding the external work required to overcome the mechanical imperfections of the apparatus, and that required to absorb the inleakage of external heat, no other work need be supplied since the expander 19, replacing expander 16, delivers enough power to operate the compressor 9. This is obvious since said expander 19 and said compressor 9 handle the same quantity of fluid at the same temperature and pressure.

It has been shown above that the process is workable under the specific conditions assumed, where the total temperature range from that at the level *a* to atmospheric is that of two or more successive substantially adiabatic compressions of a dry gas or vapor, whereby the temperature at the level *c* is fixed, once the pressures are assumed. The process, however is not in any way limited to this restriction. Heretofore it has been assumed that the vapor drawn into the compressor 6 is dry, but it is obvious that there is always some condition or state of moisture at the lower pressure, which will result in this vapor being just saturated after adiabatic compression, and it may be assumed that the fluid leaving the compressor 6 is in such a dry or saturated state that is, without superheat. Under such conditions, the liquid in passage 3 may rise to the level *c* in the interchanger; and under this condition the difference in temperature between *c* and *a* is less than under the conditions heretofore assumed, although the pressure will remain the same. It follows, since the compressor 6 may take in a wet vapor and discharge a dry saturated vapor at higher pressure, the expander 11 likewise may take in a dry saturated vapor and discharge fluid which is partly liquid; the latter, while evaporating in coil 12, may cause the condensation of just sufficient working fluid at *a*, so that the full weight of vapor need not be evaporated in coil 5, but may pass to the compressor 6 as part liquid and part vapor, in such proportions as will finally give saturated dry transfer vapor at level *c*.

From the foregoing it will be seen that the operation of my process with the apparatus shown in Fig. 1 is not in any way limited to the prevalence of particular temperature and pressure conditions in the heat transfer systems, nor to the maintenance of any definite relations between the temperatures at the levels *a* and *c*, and that at the warm end of the interchanger. It will be clear, therefore, that any temperatures at *a* and *c* may be assumed, and any corresponding pressure ranges within the heat transfer systems may be adopted. It will also be seen that the cooling effect of the high pressure vapor in passage 3, between the temperatures prevailing at the level *c* and at the atmosphere, is always sufficient, if collected in a substantially reversible manner and applied in a substantially reversible manner, to cool the low pressure vapor in passage 1 from the temperature at *c* to that at *a*, even though the specific means, as heretofore shown and described, be varied over a wide range of pressures and temperatures. It will also be evident that these results depend in no way on the specific substance employed except that it be a fluid.

The foregoing detailed explanation of the operation of my process, in connection with the particular type of apparatus shown in Fig. 1, is chiefly useful in graphically demonstrating the principles underlying my invention, by virtue of which all of the several heat exchanging actions are caused to take place in a substantially reversible manner, whereby the process can be carried out with a minimum expenditure of power. Obviously, I am in no sense limited to the use of apparatus of this character, nor even remotely resembling the same, in the sense that the various heat exchanging actions may be as clearly and definitely traced out and shown to be substantially reversible in character. In fact, I now contemplate, as a much simpler and more practical form of apparatus suitable for the application of the aforesaid principles, the modified form of apparatus shown in Fig. 3 of the drawings, which will be shown to be substantially the equivalent, in all respects, of the apparatus shown in Fig. 1, although not as susceptible to actual demonstrative proof of the actions occurring therein, as is said first described apparatus. The final result as regards the working fluid, however, is the same in both cases.

Referring to Fig. 3, the incoming gaseous fluid is taken into the passage 1 of an interchanger 2 at atmospheric, or only a nominal, pressure, as before, and is passed through the liquid state with an increase of pressure by the pump 4 before being evaporated in the passage 3 at the level *b*—*c*. The apparatus herein shown for effecting the transfer of heat from the level *a* to the level *b*—*c* in order to evaporate the liquid at said upper level and to condense the vapor near the lower level is substantially the same as previously described in connection with Fig. 1, although it will be ap-

parent that the circulation of the transfer fluid, and the weight of said fluid passing through a part of the system is to some extent varied, owing to the particular relations existing between said system and other portions of the apparatus, as hereinafter pointed out. The coil 21 corresponds to the coil 5 of the first described form (but is extended above the level *a* up to the level *b*—*c*, so that its cooling effect may be applied to the low pressure vapor between the levels *a* and *b*—*c*. The heat transfer fluid, which may be assumed to be of the same nature as the working fluid, after circulation through this coil, is led to the compressor 22, working at substantially the same pressure as pump 4, and thence through a coil 23, leaving which it is expanded through a nozzle 24 and returned to the coil 21 in the manner previously described. The evaporation of the high pressure liquid at the level *b*—*c* is thus effected. As in the former case the coils 21 and 23 are shown merely for the sake of clearness, it being obvious that the circulating fluid could be withdrawn directly from the fluid in the passages 1 and 3 of the interchanger.

In order to apply the excess cooling effect of the high pressure vapor, a coil 25, corresponding substantially to the coil 10 of Fig. 1, may be disposed in the passage 3. The fluid circulating through coil 25 may come from a high pressure compressor 26, working at a pressure corresponding substantially to the critical pressure of said fluid; leaving the compressor, it is cooled to atmospheric temperature by a water cooler 27, before entering the coil 25. From the coil 25 the compressed and cooled circulating fluid expands in an expansion engine 28, and the low pressure exhaust from said engine is led to the inlet side of the compressor 22, where it is mixed at 30 with the fluid drawn in by said compressor from the coil 21. The fluid thus circulated by compressor 26 is returned thereto through a coil 29 in the low pressure passage 1 of the interchanger, which is connected at 31 with the exhaust side of compressor 22. The system above described, comprising the compressor 26, coils 25 and 29, and expander 28 may handle in a given period of time a weight of fluid somewhat greater than the weights of working fluid entering the passage 1 during the same time, at atmospheric pressure and temperature; obviously, as previously pointed out, the coils 25 and 29 are shown merely for the sake of clearness, since the fluid thus circulated could, with suitable pressure conditions, be taken from and discharged directly into the two passages 1 and 3 of the interchanger without varying in any way the ultimate result.

In the operation of the above described apparatus, the conditions illustrated in Fig. 3 may be assumed, or if desired, they may be created, simply by operating the compressor 26 so as to produce a pressure equal to or higher than the critical pressure of the transfer fluid. The said compressor and the other elements of the circulatory system connected thereto, thereby becomes an external cooling agency sufficient, in time, to effect the desired liquefaction under low pressure at the surface *a*. During this starting period the motor 18, which, during actual operation of the process, is driven by the heated high pressure evaporate from the passage 3, as in the previously described system, may be driven by steam or other external means to effect the above described operation of the compressor 26. Owing to the phenomena that a gas when approaching critical pressure becomes more and more remote from the so-called perfect state, its action being characterized by decrease in volume at a much more rapid rate than the pressure is increased, while at constant temperature, it is known that under its critical pressure a given weight of gas contains less heat than when under a much lower pressure, say atmospheric pressure. This is due to the internal energy given off by the highly compressed gas in the form of heat, in excess of that energy imparted thereto by the compressor. In the present case, therefore, the water-cooling of the fluid from the high pressure compressor 26 removes actually more heat therefrom than was given to the gas during compression, with the result that a given weight of fluid entering the coil 25 carries into the system considerably less heat than the same weight carries out of the system from the coil 29, notwithstanding the fact that the temperatures at these points are the same. As a consequence, the circulating system 25, 26, 28, 29, in addition to its function as a means for applying the cooling effect of the high pressure gases in passage 3 between the atmosphere and the level *b*—*c* to the low pressure fluid between levels *a* and *b*—*c*, as will be hereinafter more specifically set forth, also acts as a refrigerating agency to cool the incoming low pressure gas between the atmosphere and the level *b*—*c*, and to that extent constitutes the equivalent of the external refrigerating agency 13, 14, 15, 16 which is illustrated in Fig. 1. During the starting period the actions forming the essential part of the process may be realized in some degree, depending on the adjustment of the apparatus and it is not necessary to depend entirely on the fact that the heat contents of the high pressure gas is less.

When the conditions illustrated in Fig. 3 have been established, as above described, the motor 18, in the manner heretofore fully

set forth, may recover an amount of power from the high pressure exhaust gases sufficient, if desired, to operate the compressor 26, in such a manner as to effect the compression of the transfer fluid from the pressure delivered by compressor 22 to its critical pressure, or above, thus making the operation of the system continuous. The high pressure fluid in coil 25 will be cooled by the escaping high pressure vapor in passage 3, and since this fluid in coil 25 is at the critical pressure, or above, it may be cooled to the temperature prevailing at level *b*—*c* without latent heat, and therefore in a continuous and substantially reversible manner, since there is no point where the heat must be made to flow from a substance at a stationary temperature to one which is rising in temperature. As shown in the drawing, between atmospheric temperature and that at *b*—*c*, the fluid in the transfer system flows countercurrent; however, since the working fluid in the passages 1 and 3 also flows countercurrent between these temperatures, it is evident that if the high pressure working fluid in 3 requires more heat to warm it from *b*—*c* to atmospheric than the low pressure fluid in 1 must lose to be cooled from atmospheric to *b*—*c*, this difference is compensated for by the countercurrent flow of the transfer fluid. As pointed out in my copending application Serial No. 11,850, this difference in heat capacity between the countercurrent fluids in passages 1 and 3 is present, being due to the increased specific heat of the vapor in passage 3. Being also present in the combined external cooling agency and vapor heat transfer system herein described, it is clear that, considered between the level *b*—*c* and the atmospheric level, the difference above set forth balances any difference in the opposite direction between the fluids in the coils 25 and 29.

It having been shown that the excess cooling effect of the high pressure vapor in passage 3 can be transferred to the fluid in system 25, 26, 28, 29, it remains only to apply this cooling effect where it is most needed, namely, to the low pressure incoming gases between the levels *a* and *b*—*c*. The fluid in the vapor heat transfer system having been expanded from the critical pressure to the low pressure prevailing in passage 1, by means of the expander 28, and having been cooled in coil 25 below the critical temperature, it will become wet during expansion, and if this expansion is adiabatic with the production of external work in the expander 28, about half of the fluid will be liquid after the expansion, at a temperature corresponding to the temperature at level *a*. When mixed with the vapor passing from the coil 21 to the compressor 22, the whole may reach a composition just corresponding to the saturated state after an adiabatic compression by the compressor 22. In other words, superheating of the transfer fluid used in system 21, 22, 23, 24 is prevented by this admixture; that portion of the mixture passing to coil 23 effects the evaporation of liquid at level *b*—*c* and is itself condensed; its further cooling, by expansion in the nozzle 24, not only causes it, in the coil 21, to condense a like weight of fluid in passage 1, but also enables it to effect the cooling of said fluid in passage 1 from the temperature *b*—*c* to the temperature *a*.

By analogy with the apparatus shown in Fig. 1, with reference to the two independent circulatory systems therein shown, it will be apparent that if the cooling effect of the fluid from coil 10 after expansion through expander 11 were applied, as by heat interchange but without admixture, to the transfer fluid on the suction side of compressor 6, then the two coils 5 and 12 of Fig. 1 could be combined, thus applying this cooling effect to the cooling of the low pressure working fluid between the levels *a* and *c*. The action taking place in the apparatus shown in Fig. 3 closely approximates the action which would take place under the conditions assumed above, which, clearly, correspond exactly to the actual working conditions heretofore described with reference to the apparatus of Fig. 1. It will be seen, therefore, that the admixture of these two circulating transfer fluids in effect imparts a portion of the refrigerative action of the system 25, 26, 28, 29 to the system 21, 22, 23, 24, this being evident since the cooling effect of the first mentioned system is greatly increased owing to the wide pressure range through which it operates.

As will be apparent, the remainder of the discharge from compressor 22, consisting of saturated compressed vapor at a temperature corresponding to the level *b*—*c* in passing through coil 29, cools the incoming low pressure working fluid from atmospheric temperature to the temperature *b*—*c*, thus replacing the external cooling agency 13, 14, 15, 16 of Fig. 1.

While in the present case it is not possible to demonstrate or prove graphically that the actions above described actually take place, as was the case in the system illustrated in Fig. 1, yet it is clear that the two systems, as above described, are based on precisely the same principles, and it is equally true that, by properly proportioning the weights, pressures and temperatures of the circulating and working fluids, all the actions herein described as taking place can be made substantially reversible, as was the case with the system shown in Fig. 1. It will be obvious that by increasing to the necessary extent the weight of transfer fluid circulated by the combined heat transfer and refrigerating system 25, 26, 28, 29, the necessary

cooling to make up for the mechanical imperfections of the system may be supplied, it being assumed, as in the former case, that the apparatus is effectually insulated from the inleakage of external heat. The power required to operate the transfer compressor 22 is furnished, in part at least, by the expander 28, working at the same lower temperature as said compressor and between a much greater range of pressures. The motor 18, utilizing the high pressure gases which have been increased in their available power by heating in the heater 17, may furnish the power for the compressor 26, it being clear that whatever external work is required can be supplied by the heat added at 17. As in the previous case, the nozzle 24, in theory at least, will furnish the power to drive the pump 4.

With reference to the applicability of the process, as above described, to the efficient production of power, and irrespective of its utility for refrigeration, liquefaction and separation purposes, it will be seen that since the gaseous motive fluid is enabled to issue from the prime mover 18 in the same condition as that at which it entered the interchanger, viz., at atmospheric temperature and pressure, the tremendous losses of efficiency, which characterize other vapor expansion power cycles, are avoided; in comparison, for instance, with the usual steam cycle, the present process is far more efficient, since the former necessarily labors under the handicap of being unable to restore the motive fluid to its original condition with a corresponding extraction of power, *i. e.*, the latent heat of evaporation is largely irrecoverable. In the present system, however, the latent heats substantially balance; most of the heat added at 17 is converted into work.

While the steps of the process, as applied to the liquefaction of the working fluid, have been so far described as applying to the taking in of the working fluid at low pressure, and its delivery at high pressure, it is obvious that the process as a whole possesses the characteristic of reversibility. In this connection, referring again to Fig. 1, if it be assumed that fluid under high pressure enters passage 3, and discharges from 1 at atmospheric pressure; that the external cooling agency 13, 14, 15 and 16 be omitted; and that each expansion device 8 and 11 works as a compressor and each compressor 4, 6 and 9 becomes an expander; then clearly there is an increase in the amount of work delivered by 9, working at relatively high temperature, over the corresponding element present in liquefaction systems of the prior art, and there is a net cooling effect produced between the temperature at *c* and that of the atmosphere. It will be seen, therefore, that certain of the actions and steps characteristic of the process may with advantage be applied to the liquefaction and separation systems of the prior art, and it is to be understood that my invention clearly contemplates the foregoing, and is not in any sense limited to a system wherein the outgoing fluid is at higher pressure than the incoming fluid.

In Fig. 4 I have illustrated diagrammatically the application of certain of the novel steps hereinbefore mentioned to a liquefaction cycle of the usual type, wherein the working fluid undergoes high initial compression by a compressor 32, and by means of a water cooler 33 is caused to enter the interchanger passage 34 at atmospheric temperature, but under such high pressure. In the manner common to such prior systems, a portion of this high pressure vapor is expanded through an expander 35 and, after such expansion, is returned in countercurrent through interchanger passage 36, issuing from the warm end thereof at atmospheric temperature and pressure. The cooling effect of this expanded vapor portion is thus applied to assist in the liquefaction of the high pressure fluid in passage 34, as indicated in said figure. In the manner common to such prior systems, expansion of the high pressure liquid through a nozzle 37, or equivalent device, enables the low pressure liquid thus formed in passage 36, when evaporated, to afford the necessary cooling effect by heat interchange, to render the process continuous. The apparatus thus far described, while wholly diagrammatic in character, and therefore obviously susceptible to wide variation, is typical of prior art liquefaction cycles in so far as it may be said to illustrate the basic principles and actions underlying their operation; and it will be apparent that due to the much greater specific heat of the incoming high pressure fluid, between atmospheric temperature and the temperature at *e* where condensation occurs, a given weight of countercurrent low pressure vapor in passage 36 is called upon to take out from the same weight of high pressure incoming fluid more heat per degree of temperature than it can absorb. Notwithstanding this deficiency of cooling effect between the above temperatures, there is an excess cooling effect between the levels *d* and *e*; therefore, in accordance with my invention a circulatory system, or other equivalent heat transferring agency, in the present instance shown as consisting of coils 38 and 39, compressor 40 and expander 41, connected as shown, may with advantage be employed to supplement the cooling effect upon the incoming fluid between the temperature *e* and the atmosphere. The compressor 40 may handle an amount of fluid equivalent to the working fluid handled by compressor 32 and may

work at the same pressure as the compressor 32. The circulating fluid, after expansion and cooling in expander 41, is drawn by the suction of compressor 40 through coil 38, and may be sub-cooled therein, to such a point that its subsequent compression will be without superheating, *i. e.*, the exhaust from the compressor will be at temperature *a*. In passing under high pressure through the coil 39, it cools the incoming high pressure vapor in passage 34 and is itself warmed thereby to atmospheric temperature; and thereafter is expanded for the purpose of repeating the above described cycle. In this way the cooling and liquefaction of the high pressure incoming fluid is promoted; and the expander 41, since it works at atmospheric temperature, actually returns a much greater amount of work than the low temperature expander 35, or the expander 11 of Fig. 1.

The refrigerative effect of the process may be utilized in various ways, in the manner common to processes of this class. For example, the low pressure liquefied working fluid may be withdrawn through a valve 42, or the high pressure liquid may be withdrawn through a valve 43, as shown clearly in Figs. 1 and 3.

An essentially valuable feature of the process herein described in connection with Figs. 1 and 3, as compared to processes heretofore known, resides in the fact that the working fluid may be condensed and separated, if desired, under high pressure; moreover if the outgoing fluid from a liquefaction or separation system using my process were expanded through an expander, such as the expander 19 of Fig. 2, the system would require for its operation the expenditure of only a very small proportion of the power required to operate ordinary systems of the same capacity. Obviously, the power thus required would be entirely independent of any power recovered, as above described, by the use of external heat.

As applied to the simple compression of a gas, for any purpose whatsoever, the present process permits the use of substantially adiabatic compressors and expanders working below atmospheric temperature. In the form of apparatus shown in Fig. 3, the compressor 26 may be made very small, since it operates with a fluid already under high compression, and thus it may be much more nearly isothermal in its action than the high pressure compressors used in the ordinary processes for the direct preliminary compression of the fluids therein used. The exhaust from motor 18 may, if desired, be returned through the interchanger for use over and over in the system, as indicated in Fig. 3.

I claim:

1. A process of the character set forth, comprising the circulation of a gaseous working fluid in countercurrent to effect heat interchange between heat absorbing and heat rejecting portions thereof, and the application of the cooling effect of the heat absorbing portion between given temperatures to effect the cooling of the heat rejecting portion between other temperatures.

2. A process of the character set forth, comprising the circulation of a gaseous working fluid in countercurrent to effect heat interchange between heat absorbing and heat rejecting portions thereof, and the application of the cooling effect of the heat absorbing portion at a high temperature to cool the heat rejecting portion at a lower temperature.

3. A process of the character set forth, comprising the circulation of a gaseous working fluid in countercurrent to effect heat interchange between incoming and outgoing portions thereof, the cooling of the incoming fluid between given temperatures by heat exchange with a circulating fluid, and the cooling of said circulating fluid by heat exchange with the outgoing fluid between other temperatures.

4. A process of the character set forth, comprising the circulation of a gaseous working fluid in countercurrent to effect heat interchange between incoming and outgoing portions thereof, the cooling of the incoming fluid between lower temperatures by heat exchange with a circulating fluid, and the cooling of said circulating fluid by heat exchange with the outgoing fluid between higher temperatures.

5. A process of the character set forth, comprising the countercurrent circulation of a working fluid to effect heat interchange between heat absorbing and heat rejecting portions thereof, and the liquefaction of said heat rejecting portion under atmospheric pressure, by transfer of its heat contents to said heat absorbing portion under a higher pressure.

6. A process of the character set forth, comprising the circulation of a gaseous working fluid in countercurrent to effect heat interchange between incoming and outgoing portions thereof, and the transfer of heat extracted at low temperature from one of said portions to the other of said portions at a higher temperature.

7. A process of the character set forth, comprising the circulation of a gaseous working fluid in countercurrent to effect heat interchange between heat absorbing and heat rejecting portions thereof, and the transfer of heat extracted at a given temperature from said heat rejecting portion to said heat absorbing portion at a different temperature.

8. A process of the character set forth, comprising the extraction of latent heat of

condensation from the working fluid by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after such extraction, removing the superheat from said circulating fluid, and transferring said extracted heat to the liquefied working fluid after the pressure thereon has been raised.

9. A process of the character set forth, comprising the extraction of latent heat of condensation from the working fluid by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after such extraction, cooling said circulating fluid before raising the pressure thereon, to prevent its superheating, and transferring said extracted heat to the liquefied working fluid after the pressure thereon has been raised.

10. A process of the character set forth, comprising the extraction of latent heat of condensation from the working fluid by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after such extraction, removing the superheat from said circulating fluid, condensing said circulating fluid by transfer of said extracted heat to the liquefied working fluid after the pressure thereon has been raised, and reducing the pressure on said circulating fluid.

11. A process of the character set forth, comprising the extraction of latent heat of condensation from the working fluid by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after such extraction, cooling said circulating fluid before raising the pressure thereon, to prevent its superheating, condensing said circulating fluid by transfer of said extracted heat to the liquefied working fluid after the pressure thereon has been raised, and reducing the pressure on said circulating fluid.

12. In the herein described process of refrigeration, employing a liquefied gas, the extraction of the latent heat of condensation from the gas undergoing liquefaction by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after said extraction, removing the superheat of compression from said circulating fluid, and transferring the heat previously absorbed by said circulating fluid to the liquid produced by the process after the pressure of said liquid has been raised.

13. In the herein described process of refrigeration, employing a liquefied gas, the extraction of the latent heat of condensation from the gas undergoing liquefaction by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after said extraction, cooling said circulating fluid before raising the pressure thereon, to prevent its superheating, and transferring the heat previously absorbed by said circulating fluid to the liquid produced by the process after the pressure of said liquid has been raised.

14. A process of the character set forth, comprising the liquefaction of a gaseous working fluid under atmospheric pressure, the raising of the pressure on the liquid thus formed, the evaporation of said liquid under its increased pressure and the transfer of heat from the gaseous working fluid undergoing liquefaction at a low temperature to said high pressure evaporate at a higher temperature.

15. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the circulation of the evaporate from the liquefied fluid in countercurrent to the gaseous fluid undergoing liquefaction and the transfer of heat from the latter, between given temperatures, to said evaporate between other temperatures.

16. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, increasing the pressure on the liquid thus formed, transferring the latent heat of condensation of the fluid being liquefied to the liquid under such increased pressure to effect its evaporation, and applying the cooling effect of said evaporate at higher temperature to cool the gaseous working fluid at a lower temperature.

17. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, increasing the pressure on the liquid thus formed, transferring the latent heat of condensation of the fluid being liquefied to the liquid under such increased pressure to effect its evaporation, transferring to said evaporate, at a higher temperature, the heat extracted from the gaseous working fluid at a lower temperature, and expanding said evaporate in an expansion engine.

18. A process of the character set forth, comprising the liquefaction of a gaseous working fluid under low pressure, increasing the pressure on the liquid thus formed, transferring the latent heat of condensation of the fluid being liquefied to the liquid under such increased pressure to effect its evaporation, and cooling the low pressure gaseous working fluid to the temperature of low pressure liquefaction by means of said high pressure evaporate.

19. A process of the character set forth, comprising the liquefaction of a gaseous working fluid under low pressure, increasing the pressure on the liquid thus formed, transferring the latent heat of condensation of the fluid being liquefied to the liquid under such increased pressure to effect its evaporation, cooling the low pressure gaseous working fluid to the temperature of low pressure liquefaction by means of said high pressure evaporate, adding external

heat to said high pressure evaporate, and expanding the same to perform useful work.

20. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the raising of the pressure on the liquid thus formed, the evaporation of said high pressure liquid by heat exchange with a circulating fluid, the application of the cooling effect of said evaporate to said circulating fluid, and the cooling and condensation of the gaseous working fluid by means of said circulating fluid.

21. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the raising of the pressure on the liquid thus formed, the evaporation of such high pressure liquid by heat exchange with a circulating fluid under pressure, the release of pressure from said circulating fluid, the circulation thereof in heat exchanging relation to the fluid being condensed, and the application of the cooling effect of the high pressure evaporate to said circulating fluid.

22. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the raising of the pressure on the liquid thus formed, the transfer of latent heat from said gaseous working fluid undergoing liquefaction to the liquid under increased pressure, to effect its evaporation, the extraction of the cooling effect of said high pressure evaporate by heat exchange with a circulating fluid, the further cooling of said circulating fluid by expansion, and the application of its cooling effect to the cooling and condensation of the gaseous working fluid by the aforesaid transfer of latent heat.

23. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the raising of the pressure on the liquid thus formed, the transfer of latent heat from said gaseous working fluid undergoing liquefaction to a circulating fluid, the compression of said circulating fluid, the transfer of the heat absorbed thereby to effect the evaporation of the liquid under increased pressure, the extraction of the cooling effect of said high pressure evaporate by heat exchange with a second circulating fluid, and the cooling of the first circulating fluid, before compression thereof, by said second circulating fluid.

24. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the raising of the pressure on the liquid thus formed, the transfer of latent heat from said gaseous working fluid undergoing liquefaction to a circulating fluid, the compression of said circulating fluid, the transfer of the heat absorbed thereby to effect the evaporation of the liquid under increased pressure, the extraction of the cooling effect of said high pressure evaporate by heat exchange with a second circulating fluid, and the admixture of said second circulating fluid with said first circulating fluid, before compression of the latter.

25. In a process of the character set forth, the circulation of a portion of the working fluid under atmospheric pressure, countercurrent to another portion under high pressure, the cooling and liquefaction of said first portion by heat exchange with circulating fluids, and the transfer of the heat absorbed by said circulating fluids to said high pressure portion.

26. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the raising of the pressure on the liquid thus formed, the transfer of latent heat from said gaseous working fluid undergoing liquefaction to a circulating fluid, the compression of said circulating fluid, the transfer of the heat absorbed thereby to effect the evaporation of the liquid under increased pressure, the extraction of the cooling effect of said high pressure evaporate by heat exchange with a second circulating fluid, and the cooling of the first circulating fluid by said second circulating fluid.

27. A process of the character set forth, comprising the countercurrent circulation of a gaseous working fluid, to effect heat interchange between incoming and outgoing portions thereof, the discharge of said outgoing portion at a higher pressure than said incoming portion, the circulation of a fluid in heat exchanging relation to said incoming and outgoing portions, the compression of said last named fluid at a temperature below atmospheric, and the further compression of a portion of said last named fluid at a temperature above atmospheric.

28. A process of the character set forth, comprising the countercurrent circulation of a gaseous working fluid, to effect heat interchange between incoming and outgoing portions thereof, the discharge of said outgoing portion at a higher pressure than said incoming portion, and the transfer of heat from one portion to the other by successive compressions of a circulating fluid, below and above atmospheric temperature.

29. In a process of the character set forth, the countercurrent circulation of incoming and outgoing portions of a gaseous working fluid, the circulation of a fluid in heat exchanging relation to both of said portions, and the successive compression of said circulating fluid below and above atmospheric temperature, to effect the compression of said outgoing portion.

30. A process of the character set forth, comprising the circulation of a working fluid in countercurrent to itself to effect heat interchange between heat absorbing and heat rejecting portions thereof, and the

liquefaction of said heat rejecting portion under low pressure by transfer of its heat contents to said heat absorbing portion.

31. A process of the character set forth, comprising the circulation of a working fluid in countercurrent to itself to effect heat interchange between heat absorbing and heat rejecting portions thereof, and the liquefaction of said heat rejecting portion under atmospheric pressure by transfer of its heat contents to said heat absorbing portion.

32. A process of the character set forth, comprising the circulation of a working fluid in countercurrent to itself to effect heat interchange between heat absorbing and heat rejecting portions thereof, and the liquefaction of said heat rejecting portion under low pressure by transfer of its heat contents to said heat absorbing portion under a higher pressure.

33. A process of the character set forth, comprising the extraction of latent heat of condensation from a gaseous working fluid by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after such extraction, removing the superheat from said circulating fluid, and transferring said extracted heat to the liquefied working fluid.

34. A process of the character set forth, comprising the extraction of latent heat of condensation from a gaseous working fluid, by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after such extraction, cooling said circulating fluid before raising the pressure thereon, to prevent its superheating, and transferring said extracted heat to the liquefied working fluid.

35. A process of the character set forth, comprising the extraction of latent heat of condensation from a gaseous working fluid, by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after such extraction, removing the superheat from said circulating fluid, condensing said circulating fluid by transfer of said extracted heat to the liquefied working fluid, and reducing the pressure on said circulating fluid before its return into heat exchanging relation to the working fluid undergoing liquefaction.

36. In the herein described process of refrigeration, employing a liquefied gas, the extraction of the latent heat of condensation from the gas undergoing liquefaction by heat exchange with a circulating fluid, raising the pressure of said circulating fluid after said extraction, removing the superheat of compression from said circulating fluid, and transferring the heat previously absorbed by said circulating fluid to the liquid produced by the process.

37. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the evaporation of said liquefied working fluid, and the transfer of heat from the gaseous working fluid undergoing liquefaction at a low temperature to said evaporate at a higher temperature.

38. A process of the character set forth, comprising the liquefaction of a gaseous working fluid under atmospheric pressure, the evaporation of said liquefied working fluid, and the transfer of heat from the gaseous working fluid undergoing liquefaction at a low temperature to said evaporate at a higher temperature.

39. A process of the character set forth, comprising the liquefaction of a gaseous working fluid under a low pressure, the evaporation of said liquefied fluid without releasing the pressure thereon, and the transfer of heat from the gaseous working fluid undergoing liquefaction, between given temperatures, to said evaporate between other temperatures.

40. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the evaporation of the liquid thus produced, and the application of the cooling effect of said evaporate, between given temperatures, to cool the gaseous working fluid undergoing liquefaction between other temperatures.

41. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the evaporation of the liquid thus produced, and the transfer of heat extracted from the gaseous working fluid at a low temperature to said evaporate at a higher temperature.

42. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, evaporating the liquid thus produced, and cooling the gaseous working fluid to the liquefaction temperature by means of said evaporate at a higher temperature.

43. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the evaporation of the liquefied portion thus produced, and the transfer of heat extracted from the gaseous working fluid at a low temperature to said evaporate at a higher temperature.

44. A process of the character set forth, comprising the liquefaction of a gaseous working fluid, the evaporation of the liquid thus produced by heat exchange with a circulating fluid, the application of the cooling effect of said evaporate to said circulating fluid, and the cooling and condensation of the gaseous working fluid by means of said circulating fluid.

45. A process of the character set forth, comprising the liquefaction of a gaseous working fluid under low pressure, the evaporation of the liquid thus formed without release of pressure by heat exchange with a

circulating fluid, and the cooling and condensation of the gaseous working fluid by means of said circulating fluid.

46. In a process of the character set forth, the circulation of a portion of the working fluid under low pressure in countercurrent to another portion under higher pressure, the cooling and liquefaction of said first portion by heat exchange with a plurality of circulating fluids, and the transfer of the heat absorbed by said circulating fluids to said high pressure portion.

47. In a process of the character set forth, comprising countercurrent circulation between heat absorbing and heat rejecting portions of a gaseous working fluid, the cooling and liquefaction of the heat rejecting portion by heat exchange with circulating fluids, and the transfer of the heat absorbed by said circulating fluids to said heat absorbing portion.

48. In a process of the character set forth, the countercurrent circulation of heat absorbing and heat rejecting portions of a gaseous working fluid, the circulation of a heat transfer fluid in heat exchanging relation to both of said portions, and the compression of said heat transfer fluid above and below atmospheric temperature, to add heat to said heat absorbing portion and thereby to increase the pressure thereof.

49. In a process of the character set forth, the passing of a gaseous working fluid through the liquid state, by the successive compression and expansion of a heat transfer fluid circulating in heat exchanging relation to heat absorbing and heat rejecting portions of said working fluid.

50. In a process of the character set forth, the passing of a gaseous working fluid through the liquid state, by the successive compression and expansion of a portion thereof circulating in heat exchanging relation to gaseous portions before and after liquefaction.

51. In a process of the character set forth, the passing of a gaseous working fluid through the liquid state, and the maintenance of pressure on the evaporate therefrom, by the successive compression and expansion of a heat transfer fluid circulating in heat exchanging relation to said evaporate and to the fluid undergoing liquefaction.

52. In a process of the character set forth, the passing of a gaseous working fluid through the liquid state, and the increase of pressure on the evaporate therefrom, by the successive compression and expansion of a heat transfer fluid circulating in heat exchanging relation to said evaporate and to the fluid undergoing liquefaction.

53. In a process of the character set forth, the passing of a gaseous working fluid through the liquid state, and the maintenance of pressure on the evaporate therefrom, by the successive compression and expansion of a portion thereof circulating in heat exchanging relation to said evaporate and to the fluid undergoing liquefaction.

54. In a process of the character set forth, the passing of a gaseous working fluid through the liquid state, and the increase of pressure on the evaporate therefrom, by the successive compression and expansion of a portion thereof circulating in heat exchanging relation to said evaporate and to the fluid undergoing liquefaction.

Dated this 27th day of January, 1916.

FRED E. NORTON.

Witnesses:

PENELOPE COMBERBACH,

NELLIE WHALEN.