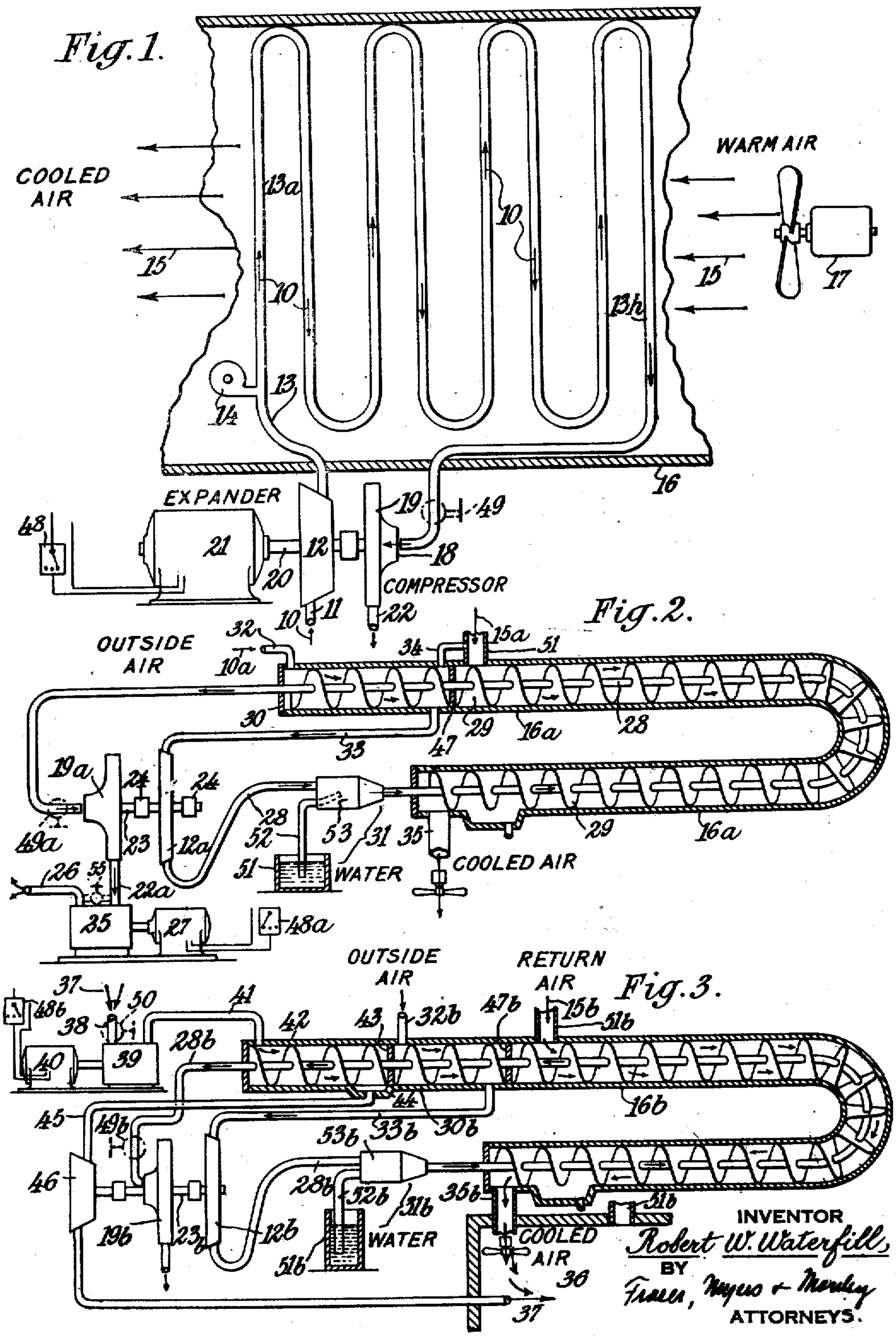
Oct. 3, 1939. R. W. WATERFILL 2,175,162

METHOD AND APPARATUS FOR COOLING MEDIA

Filed Feb. 15, 1937



INVENTOR
Robert W. Waterfill,
BY
Fraser, Myers & Manley
ATTORNEYS.

Patented Oct. 3, 1939 2,175,162

UNITED STATES PATENT OFFICE

2,175,162

METHOD AND APPARATUS FOR COOLING MEDIA

Robert W. Waterfill, East Orange, N. J., assignor to Buensod-Stacey Air Conditioning, Incorporated, New York, N. Y., a corporation of Delaware

Application February 15, 1937, Serial No. 125,823

22 Claims. (Cl. 62—136)

This invention relates to improved methods of, and apparatus for, cooling various media, and in its more particular aspects it has to do with the application of these methods to the cooling of enclosures, either for human comfort or for the control of various industrial processes being carried out in such enclosures.

The general method of the present invention is an evaporative one in which a gaseous fluid is presented to an unchilled liquid surface in such fashion as to achieve substantial saturation of the fluid with vapors of the liquid, and a consequent sensible cooling, by evaporation, to the wet bulb temperature of the incoming fluid.

Such a method, as so far described, is well known, and while its application is not limited to any particular class of work, it has been most widely used in cooling air by saturating the latter with water vapor. For purposes of description the present method will be considered principally as relating to air cooling; and the gaseous fluid will be referred to as air, and the liquid as water. However, this particular application, and the fluids described, are illustrative only, since the method may be applied to any cooling problem, and, any fluid and any liquid might be used.

The degree of cooling (final temperature obtained) which may be achieved in the above manner is totally dependent upon the wet bulb temperature of the incoming air. Further, the extent of cooling, i. e., the quantity of heat which may be absorbed by the saturation of one pound of air, is dependent upon the initial wet bulb temperature, and wet bulb depression, of that air. These factors obviously are as changeable as the weather, and if any particular low temperature must be maintained, then the process, as so far described, is impractical. Moreover, presently known processes of this type are not applicable, except in rare instances, to any case in which the medium to be cooled must also be dehumidified. In any event, known processes utilizing evaporative cooling are generally limited geographically to areas in which the average wet bulb temperature is relatively low, the average wet bulb depression is relatively great, and both of these factors are fairly stable.

The principal object of the present invention is to provide improved methods utilizing the above defined principles but so modified as to avoid the limitation of prior practices while retaining all of the desirable features thereof, to wit; simplicity and cheapness of apparatus necessary to carry out the methods, and low operating and maintenance costs.

Other objects and various features of the invention will be more apparent from the following description when read in connection with the accompanying drawing, in which:

Figure 1 is a diagrammatic view, in elevation, of one form of apparatus which may be used to carry out the principles of the present invention.

Fig. 2 is a like view of an apparatus for carrying out the principles of my invention and embodies certain modifications not included in Fig. 1.

Fig. 3, similarly, is both diagrammatic and elevational, and illustrates a further modification of the apparatuses of Figs. 1 and 2.

If air at atmospheric pressure is expanded to some lower pressure then its vapor pressure will be reduced, and conversely, its capacity for absorbing water vapor will be correspondingly increased. As a concomitant of the foregoing, the dry bulb, wet bulb, and dewpoint temperatures, and the total heat content of the air will be reduced. Hence, such air may then be saturated at a lower temperature (the new wet bulb) than would otherwise be possible; and within economic limits, this temperature may be controlled at any desired point by greater or lesser initial expansion. Further, the amount of moisture which may be evaporated, and the amount of heat absorbed by such evaporation, will be increased as a result of the vapor pressure reduction; and the volume of air handled to effect the transfer of a given quantity of heat may be reduced to some extent.

The process of the present invention depends upon the foregoing principles, and may be briefly and broadly described as comprising the steps wherein air at atmospheric pressure is first expanded to some lower pressure, then saturated with water vapor at the lower pressure, and finally passed in counterflow heat exchange relation with the medium which is to be cooled. When the cooling process is completed the vapor-laden air may be thrown away, and this is accomplished by compressing such air to atmospheric pressure and discharging it.

The necessary degree of expansion in this process will in part be dependent upon existing atmospheric conditions (wet and dry bulb temperatures and barometric pressure of the incoming air), and upon the final temperature to which the medium is to be cooled. The principle of the invention is to expand to such a pressure as will result in a desired reduction of the wet bulb temperature, and in any event a very material reduction of the vapor pressure of the incoming air, whereby the heat-absorbing capacity of such air may be very materially increased. In general the process will be carried out under a vacuum of not less than one inch of mercury; and in many instances it will be found to be necessary, and desirable, to operate at vacuum varying from 5 to 15 inches of mercury.

Considering the practical operation of such a process, and referring to Fig. 1, a volume of air 10 at atmospheric pressure (termed the working medium) is intaken through pipe 11 and expanded to some desired lower pressure, through expander 12, into the closed conduit 13. Water is then sprayed into the conduit 13 by means of the injector 14, and preferably the injector and the conduit (here illustrated purely in diagrammatic form) are so arranged that the water will flow throughout the length of the conduit and keep its surfaces in substantially a wetted condition. Accordingly, as the air passes through the spray and over the wet surfaces, it will absorb moisture, and, by well-understood evaporative processes, will be cooled.

The medium to be cooled may, for example, be a second volume of air, indicated by the arrows 15, passing through a conduit 16 under the influence of a fan or other comparable device 17. The air as it passes over the outside surface of the conduit 13 will be in indirect heat-exchanging relation with the working medium, and accordingly it will give up its heat to this relatively cold substance.

The arrangement of the conduit 13 in the conduit 16 is such that the working medium passes in counter-flow heat-exchanging relation with the medium to be cooled. Specifically, that part of the medium in portion 13*a* of the conduit will be saturated with moisture at the wet bulb temperature of the medium, leaving the expander 12—the lowest temperature attained in the subatmospheric part of the process. Such medium passes through the conduit from left to right, as viewed in Fig. 1, whereas the air 15 to be cooled passes through conduit 16 from right to left. Accordingly, the temperature of the working medium, due to the absorption of heat, will constantly tend to rise, while the temperature of the air passing thereover, due to the extraction of heat therefrom, will tend constantly to decrease. In the final analysis it will be seen that the warmest air meets the warmest medium, while the coldest air is in heat exchange relation with the coldest medium.

By the foregoing arrangement, then, the temperature of the working medium tends constantly to increase. However, any such temperature rise is accompanied by an increased capacity of the medium for water vapor; and since it is constantly in contact with the wetted walls of the conduit 13, it will continue to evaporate water and absorb heat in this manner. Thus the absorption of heat by the working medium will be substantially along a saturation line, and such heat will, in large part, be converted into a latent rather than a sensible state. For any given temperature spread, then, the amount of heat absorbed will be far greater than that represented by the sensible heat gain. In this particular the present process differs greatly from any heretofore known and practiced; and, translated into terms of economy, this means that a given quantity of heat may be absorbed within a given temperature range by the circulation of a relatively small quantity of working fluid.

When the cooling process is complete, the working medium, because of its inexpensive character, may be thrown away. For this purpose, then, the conduit 13 discharges into the inlet 18 of a compressor 19, the latter being mounted upon the shaft 20 of any appropriate motor 21; and in this compressor the moisture-laden medium is compressed to atmospheric pressure whereby it may be discharged through conduit 22 to the atmosphere.

The only power necessary to operate the above-described process is that required to compress the moisture-laden working fluid to atmospheric pressures and to discharge it from the system. Such power may be derived entirely from the motor 21, if desired. However, in the preferred arrangement, the power requirement is reduced to a very appreciable extent by recovering the energy available from the initial expansion of the air, and by utilizing this energy to assist in the subsequent compression step. As here shown, this is accomplished by passing the air through expander 12 which may take the form, for example, of a turbine, the latter being mounted upon the shaft 20 of a motor 21, so that any power derived from such expansion tends to drive the compressor 19 and thus tends to reduce the amount of work expended by the motor 21.

In the modification of Fig. 1, the capacities of the compressor and expander must be rigidly proportioned one to the other; and these two elements, taken in conjunction with the motor 21, present a nice problem of balanced design. Some of the difficulties of this problem may be avoided, as illustrated in Fig. 2, by mounting the expander 12*a* and the compressor 19*a* upon a free floating shaft 23 appropriately journaled as at 24. In this modification the compressor 19*a* is driven entirely by the energy derived from the expander 12*a*. Some losses are of course inherent in any mechanical system, and consequently the energy derived from 12*a* is not sufficient to compress the working medium to the desired extent. Therefore, 19*a* is intended only to partially recompress the air; and such partially recompressed air is then discharged through conduit 22*a* into a second compressor 25, wherein compression is completed, so that the medium may be discharged to the atmosphere through conduit 26. A suitable motor 27 drives the final compressor and furnishes the balance of power necessary to complete the compression.

So much of the apparatus of Fig. 2 as has heretofore been described may be incorporated bodily into the device of Fig. 1 and used as a substitute therefor, or, if desired, the expander 12, compressor 19 and motor 21 may be substituted as a unit for the expander 12*a*, compressor 19*a*, booster compressor 25, and motor 27 of Fig. 2.

The cooling process illustrated in Fig. 2 embodies a further modification of the one disclosed by Fig. 1 in so far as the working medium is precooled prior to expansion, and in so far as the initial temperature of the working medium is somewhat higher than the initial temperature of the medium to be cooled.

The apparatus for carrying out this process is likewise somewhat modified. Thus the conduit 28, while the functional equivalent of the conduit 13, is differently constructed in that it is provided with a spiral fin 29 which makes relatively close fit with the adjacent walls of the conduit 16*a*, and the latter, for purposes of space economy, is disposed in the form of a U-bend. Moreover, the conduit 28, after passing through the conduit 16*a*, passes directly into another conduit 30 (constituting, in fact, an extension of 16a and separated therefrom only by wall 47) so that the working medium may be pre-cooled, before expansion, by contact therewith. Further, the water injector 31 of Fig. 2 is constructed and operated somewhat differently from the injector shown at 14 in Fig. 1. In this modification the pressure differential existing on the inside and outside of conduit 28 is utilized to force water from reservoir 51 through tube 52 into mixing chamber 53 wherein it meets the inrushing, high velocity, stream of expanded air 10a, and is carried along thereby throughout the length of the conduit to maintain the surfaces of the latter wetted and thus to assure constant and complete saturation of that air, as described in connection with Fig. 1.

Considering the operation of the device of Fig. 2, it will be noted that outside air, which may be assumed to have a dry bulb temperature of 95°, for example, is intaken, through inlet 32, into the conduit 30, and passes (as indicated by the arrows) in heat exchange relation with the part of conduit 28 lying therein, so as to be pre-cooled, as will later appear. Such pre-cooled air is then led through conduit 33 into expander 12a, wherein its pressure is reduced to a desired extent, in the manner hereinbefore described. The expanded air then passes through injector 31 into the conduit 28, wherein its contacts the wet walls of the conduit and becomes appropriately saturated, exactly as described in connection with Fig. 1.

The medium to be cooled, 15a, may be assumed to be air returned from an enclosure for re-cooling, and as such, may be assumed to have a dry bulb temperature of 75°. Such air may, if desired, be mixed with a small volume of outside air drawn from conduit 30, wherein it has been pre-cooled, through conduit 34. The mixture is then led through conduit 51 into conduit 16a, wherein it passes, as indicated by the arrows, counterflow to the working medium in the conduit 28, thereby giving up its heat to such medium exactly as was described in connection with Fig. 1. After being appropriately cooled it is discharged through an outlet 35 and may be conducted to any desired point of usage.

The temperature of the working medium in conduit 28 as the latter passes through the conduit 16a, will increase and will approach the inlet temperature of the air 15a as a maximum. This we have assumed to be 75 degrees, and obviously it is less than the temperature of the incoming working medium which we have taken to be at 95 degrees. Consequently, the working medium in that part of conduit 28 lying within conduit 30, is at a lower temperature than the working medium in conduit 30. Accordingly, since the two are in counterflow heat exchange relation, the temperature of the air entering through 32 will be somewhat decreased prior to its expansion at 12a, and its heat-absorbing capacity thereby increased; and the medium will be further heated and saturated with additional moisture as a result of the exchange.

Figure 3 represents still another modification of the process wherein one volume of air is cooled exactly as has been described in Fig. 2; and another volume of air, cooled in a different manner, is then mixed with the first volume to produce a final volume having a desired temperature and humidity conditions. In this modification, outside air (again assumed to be at 95°) is pre-cooled in conduit 30b, expanded to a desired pressure in 12b, saturated with water vapor in 28b, and passed in indirect counterflow, heat-exchanging relation with air 15b (in the conduit 16b) to cool the latter. The cooled air 15b is then discharged through outlet 35b into an enclosure 36.

The first volume of air, cooled as above described, is augmented by a second volume of air, indicated by the arrows 37, and cooled in the manner now to be described. This second volume may be taken from any desired source. However, if taken from the outside, as here shown, it will serve to supply ventilation requirements, thus avoiding the necessity for the by-pass conduit 34 of Fig. 2. Whatever the source, it passes through inlet 38 to compressor 39 (driven by any appropriate motor 40) wherein it is compressed to some desired super-atmospheric pressure, 10 pounds per square inch, for example. The final temperature of such compressed air will be somewhat higher than that of the working medium, in conduit 28 as the latter passes out of conduit 30b. Accordingly the medium may be further used for cooling; and heat interchange may be effected along a saturation line so as to effect a maximum transfer with a minimum temperature rise. For this purpose the compressed air is led through conduit 41, into conduit 42 (the latter constituting an extension of conduit 30 and being separated therefrom only by wall 43) and passes, as indicated by the arrows, counterflow to the working medium so as to be cooled thereby. Further, during the compression the capacity of the air for water vapor has been reduced, as is well understood by those skilled in the art, and, in fact, when it is discharged into the conduit 42 it will be in substantially a saturated condition. Accordingly, a lowering of its temperature, by the cooling above described, will result in condensation of moisture, that is, dehumidification. The resulting condensate may be collected in the well 44 and disposed of in any suitable manner.

The now compressed and dehumidified air 37 passes through conduit 45 into an expander 46, wherein its pressure is reduced substantially to atmospheric. After expansion it will, of course, be relatively cold and have a relatively low dew-point, and may be mixed with the cooled air from the outlet 35b so as to achieve a mixture having desired atmospheric properties.

It is to be noted that the expander 46 is mounted upon the shaft 23b which carries the compressor 19b and the expander 12b. Accordingly, energy released by the expansion of the air 37 will be transformed into power and will be used to supply the balance of power necessary to drive the compressor 19b, and discharge the moisture-laden working medium from the system.

Control of the degree of cooling obtainable in the sub-atmospheric portion of any of the foregoing processes may be achieved, generally speaking, by controlling the vapor pressure and wet bulb temperature of the working medium; and this, in turn, may be controlled by expanding the working fluid to a greater or lesser pressure. Such expansion control may be achieved in any one of several ways, for example, by regulating the speed of the compressor, or by the use of a throttling damper, or a by-pass damper, at some point in the working fluid path. All of these methods are illustrated in the drawing. Thus, in Fig. 1 the motor 21 is provided with a control 48 which may be a rheostat or other appropriate device, for varying the speed of this motor and thereby varying the speed at which the compressor is operated. An alternative pressure control comprising a throttling damper 49 (shown in dotted lines) is also illustrated in Fig. 1. In Fig. 2 the same results may be achieved by limiting the speed of motor 21, driving compressor 25, through controller 48*a*; or by the use of the throttling damper shown in dotted lines at 49*a*; or by the use of a by-pass damper shown in dotted lines at 55. In Fig. 3, control may be obtained by regulating the speed of motor 40, driving compressor 39, through the controller shown at 48*b*. In this latter case control of the speed of compressor 39 has two direct effects. Firstly, it limits the degree of compression of the volume of outside air 37, and hence limits the degree of cooling which may be obtained of the subsequent expansion of this volume of air; and secondly, it also limits the speed of the expander 12*b* and hence the degree of expansion of air 10*b*. Alternatively, the degree of expansion may be limited in this modification by the use of a throttling damper, and such damper may be positioned either at 49*b* or at 50, or at both places.

As has heretofore generally been pointed out, the various elements disclosed in the drawing are of a diagrammatic nature. Thus, the expanders 12, 12*a* and 46, in practice, may take any one of several forms, such as a turbine, reciprocating engine, or the like. Similarly, the compressors 19, 19*a*, 25 and 39 may be constructed in any desired manner. These elements might be of the centrifugal type, of the gear type, of the piston displacement type, or of the Roots blower type. The compressor 19*a*, for example, might be of a type entirely different from that shown at 25. The types will, in the final analysis, depend upon considerations entirely outside of the present invention, and they will be selected by those skilled in the art to provide an efficient combination of apparatus for carrying out the disclosed processes. Similarly, the conduits here shown are purely of the diagrammatic character. They are not intended to have any scale relationship but merely to illustrate the paths through which the various media pass, and the heat transfer relationships of those media. Likewise, the water injectors are of a diagrammatic character, and must necessarily be so because of the diagrammatic character of the remaining parts of the drawing.

Since certain changes and modifications may be made in the invention, some of which have been herein suggested, it is intended that the foregoing shall be construed in a descriptive rather than in a limiting sense.

What I claim is:

1. The method of cooling a medium which comprises the steps of expanding air from atmospheric to sub-atmospheric pressure of such degree as will reduce its wet-bulb temperature to a desired point, passing the medium to be cooled in counterflow heat-exchanging relation with the expanded air, maintaining the expanded air constantly in contact with an unchilled water surface throughout the interchange whereby to saturate it with water vapor at its initial wet-bulb temperature and to maintain it saturated as its wet-bulb temperature progressively increases during the heat interchange, and finally compressing the vapor laden air to atmospheric pressure.

2. The method according to claim 31, further characterized by recovering the energy of expansion of said air and utilizing such energy to assist in the subsequent compression of such air.

3. The method of cooling a medium which comprises expanding a gaseous fluid to sub-atmospheric pressure of at least five inches of mercury (vacuum) whereby to lower its wet bulb temperature to a desired extent, maintaining a flow of such expanded fluid through a closed path and in substantially constant contact with an unchilled liquid surface whereby to saturate the fluid with vapor of the liquid, passing the medium to be cooled in indirect counterflow heat exchanging relation with the saturated fluid, and finally compressing the vapor-laden fluid to atmospheric pressures and discharging it from the closed path.

4. The method of cooling a medium which comprises expanding air to sub-atmospheric pressure of such degree as will materially reduce the water vapor content and wet-bulb temperature thereof, then saturating such expanded air with water vapor by passing it through a closed path in contact with an unchilled water surface, passing the medium to be cooled through another path in indirect, counterflow, heat exchanging relation with the saturated air in the first path, and subsequently compressing the resulting vapor-laden air to atmospheric pressure and discharging the compressed air from said first closed path, said method being further characterized in that the expanded air is maintained saturated with water vapor throughout heat transfer with the medium to be cooled by maintaining such air constantly in contact with an unchilled water surface throughout such transfer.

5. The method according to claim 4, further characterized in that the air is pre-cooled, prior to expansion, by passing it in indirect counterflow heat exchanging relation with the expanded, saturated air subsequent to heat interchange between such air and the medium to be cooled and before the compression of such air.

6. The method of cooling an enclosure, which comprises compressing a first volume of air to super-atmospheric pressures, pre-cooling such compressed air, and expanding such air; expanding a second volume of air to sub-atmospheric pressures of such degree as will materially reduce its water vapor pressure, passing such expanded air through a closed path, saturating the second volume of air with water vapor and maintaining it in substantially saturated condition by the constant evaporation of water in said closed path, passing a third volume of air in indirect, counterflow, heat exchanging relation with the expanded second volume of air, compressing the resulting vapor-laden second volume of air to atmospheric pressures and discharging it from said closed path; mixing the third volume of air with the expanded first volume and discharging the mixture into the enclosure.

7. The method of cooling an enclosure, in accordance with claim 6, further characterized by the step of pre-cooling the second volume of air prior to the expansion thereof.

8. The method of cooling an enclosure, according to claim 6, further characterized in that the second volume of air prior to expansion is pre-cooled, by being passed in indirect, counterflow, heat exchange relation with the expanded, saturated air in the closed path subsequent to heat interchange between the second and third volumes of air and before compression of the second volume.

9. The method of cooling an enclosure according to claim 6, further characterized in that the second volume of air prior to expansion is pre-cooled by being passed in indirect, counterflow, heat exchange relation with the expanded, sat-

urated air in the closed path subsequent to heat interchange between the second and third volumes of air and before compression of the second volume; and the first volume of air is pre-cooled by being passed in indirect, counterflow, heat exchanging relation with the expanded, saturated air in the closed path subsequent to the pre-cooling of the second volume of air and prior to compression of such air.

10. The method of cooling an enclosure, according to claim 6, further characterized by recovering the energy resulting from the expansion of the second volume of air, and utilizing such recovered energy to assist in subsequent compression of said second volume.

11. The method of cooling an enclosure, according to claim 6, further characterized by recovering the energy resulting from the expansion of the second volume of air, utilizing such recovered energy to assist in subsequent compression of said second volume of air, and by recovering the energy of expansion of the first volume of air and utilizing such recovered energy to supply the balance of power necessary to complete the compression of the second volume of air.

12. Apparatus for cooling a medium comprising a conduit, an expander adjacent one end of the conduit adapted to expand a gaseous working medium to a desired sub-atmospheric pressure of five inches of mercury or more and to discharge the expanded air into said conduit, a compressor adjacent the other end of the conduit adapted to maintain a constant flow of working medium through the conduit and to discharge such medium from the conduit, means for driving the compressor, means for injecting liquid into said conduit at a point adjacent the expander and in such quantities as to maintain the surface of the conduit wetted substantially throughout its length, and means for passing the medium to be cooled over the surface of the conduit in counterflow heat exchange relation with the working medium.

13. Apparatus for cooling a medium according to claim 12 further characterized in that said compressor and said expander are mounted upon a common shaft whereby the energy resulting from the expansion of the working fluid may be utilized to assist in driving said compressor.

14. Apparatus for cooling a medium according to claim 12, further characterized in that the means for driving said compressor comprises said expander, and a separate motor; the former being adapted to supply part of the power necessary to compress the working medium, and the latter being adapted to supply the balance of power necessary to complete such compression.

15. Apparatus for cooling a medium comprising a first conduit, an expander adapted to expand air from atmospheric to a desired lower pressure of at least five inches of mercury (vacuum) and to discharge the expanded air into the first conduit adjacent one end thereof, means for injecting water into said first conduit at a point adjacent the expander and in sufficient quantities to maintain the surface of the conduit wetted substantially throughout its length, a compressor adapted to maintain a constant flow of air through said conduit in a desired direction and to compress and discharge the air therefrom; a second conduit adapted to serve as a path for a medium to be cooled, means for passing such medium through said second conduit in a direction opposite to the direction of flow in the first conduit; said conduits being so disposed with respect to each other that the air in the first one will pass in indirect, counterflow, heat exchanging relation with the medium to be cooled in the second one.

16. Apparatus for cooling a medium according to claim 15, further characterized by the provision of a third conduit adapted to serve as a path for air prior to the expansion of such air into the first conduit, said third conduit being so disposed with respect to the first and second ones, that air in the first conduit subsequent to heat exchange with the medium to be cooled in the second conduit will pass in indirect counterflow heat exchange relation with the air in the third conduit.

17. Apparatus for cooling an enclosure, comprising a first compressor adapted to compress a first volume of outside air from atmospheric to a desired superatmospheric pressure, means for precooling such compressed air, a first expander adapted to expand such air substantially to atmospheric pressure and to discharge it into the enclosure to be cooled; a first conduit defining a closed path for a second volume of outside air, means for pre-cooling such second volume of air, a second expander adapted to expand said second volume of air from atmospheric to a desired subatmospheric pressure, means for injecting water into said first conduit whereby to cool the air therein by evaporation, and a compressor adapted to maintain a flow of air through said first conduit in a desired direction and to compress and discharge said air therefrom; a second conduit disposed in heat exchange relation with the first one, means for withdrawing air from the enclosure, means for passing said withdrawn air through the second conduit in a direction counter to the flow of medium through the first one, and means for discharging the withdrawn air from the second conduit into said enclosure.

18. Apparatus for cooling an enclosure according to claim 17, further characterized in that the means for pre-cooling the second volume of air prior to expansion comprises a third conduit so disposed with respect to the first one that unexpanded air in the former will pass in indirect counterflow, heat exchange relation with expanded air in the latter, subsequent to the heat exchange between the latter and the withdrawn air.

19. Apparatus for cooling an enclosure according to claim 17, further characterized in that the means for pre-cooling the second volume of air prior to expansion comprises a third conduit so disposed with respect to the first one that unexpanded air in the former will pass in indirect counterflow, heat exchange relation with expanded air in the latter, subsequent to the heat exchange between the latter and the withdrawn air; and the means for pre-cooling the compressed first volume of outside air comprises a fourth conduit so disposed with respect to the first, second and third ones that the compressed air passes in indirect, counterflow, heat exchange relation with the expanded second volume of air subsequent to the heat exchange between the latter and the withdrawn air, and to the heat exchange between the latter and the unexpanded second volume of air.

20. Apparatus for cooling an enclosure according to claim 17, further characterized in that both said first and second expanders are motors capable of converting the energy of expansion of said first and second volumes of air into mechanical work,

and means connecting both of said expanders to said second compressor whereby to drive the latter.

21. The method of cooling a medium which comprises expanding air to sub-atmospheric pressure so as to reduce its vapor pressure and wet-bulb temperature to a desired point, controlling such vapor pressure and wet bulb temperature by controlling the degree of such expansion, saturating the expanded air with water vapor by passing it through a closed path constantly in contact with an unchilled water surface, and subsequently compressing the vapor-laden air to atmospheric pressures and discharging it from the closed path; and passing the medium to be cooled through another path in indirect, counterflow, heat exchange relation with the saturated air in the first path.

22. Apparatus for cooling a medium comprising a first closed conduit, an expander adapted to expand air from atmospheric to some desired lower pressure and to discharge the expanded air into the conduit adjacent one end thereof, means for injecting water into said first conduit at a point adjacent the expander and in such quantity as will maintain the surface of the conduit wetted substantially throughout its length, a compressor adapted to maintain a constant flow of such expanded air through said conduit in a desired direction and to compress and discharge the air therefrom, and means for controlling the lower pressure to which said air is expanded; a second conduit adapted to serve as a path for a medium to be cooled, means for passing such medium through said second conduit in a direction opposite to the direction of flow in the first conduit, said conduits being so disposed with respect to each other that the air in the first one will pass in indirect, counterflow, heat exchanging relation with the medium to be cooled in the second one.

ROBERT W. WATERFILL.

CERTIFICATE OF CORRECTION.

Patent No. 2,175,162. October 3, 1939.

ROBERT W. WATERFILL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, first column, line 70, claim 2, for the claim reference numeral "31" read 1; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 7th day of November, A. D. 1939.

Henry Van Arsdale,
Acting Commissioner of Patents.

(Seal)

and means connecting both of said expanders to said second compressor whereby to drive the latter.

21. The method of cooling a medium which comprises expanding air to sub-atmospheric pressure so as to reduce its vapor pressure and wet-bulb temperature to a desired point, controlling such vapor pressure and wet bulb temperature by controlling the degree of such expansion, saturating the expanded air with water vapor by passing it through a closed path constantly in contact with an unchilled water surface, and subsequently compressing the vapor-laden air to atmospheric pressures and discharging it from the closed path; and passing the medium to be cooled through another path in indirect, counterflow, heat exchange relation with the saturated air in the first path.

22. Apparatus for cooling a medium comprising a first closed conduit, an expander adapted to expand air from atmospheric to some desired lower pressure and to discharge the expanded air into the conduit adjacent one end thereof, means for injecting water into said first conduit at a point adjacent the expander and in such quantity as will maintain the surface of the conduit wetted substantially throughout its length, a compressor adapted to maintain a constant flow of such expanded air through said conduit in a desired direction and to compress and discharge the air therefrom, and means for controlling the lower pressure to which said air is expanded; a second conduit adapted to serve as a path for a medium to be cooled, means for passing such medium through said second conduit in a direction opposite to the direction of flow in the first conduit, said conduits being so disposed with respect to each other that the air in the first one will pass in indirect, counterflow, heat exchanging relation with the medium to be cooled in the second one.

ROBERT W. WATERFILL.

CERTIFICATE OF CORRECTION.

Patent No. 2,175,162. October 3, 1939.

ROBERT W. WATERFILL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 4, first column, line 70, claim 2, for the claim reference numeral "31" read 1; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 7th day of November, A. D. 1939.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.